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(54) Title: EQUIPMENT SERVICE VEHICLE WITH REMOTE MONITORING

(57) Abstract: A system comprises an equipment service vehicle and an off-board computer system. The equipment service vehicle further includes a power source, a power transmission link, a plurality of input devices, a plurality of output devices, and an on-board computer system. The on-board computer system further includes a plurality of microprocessor-based interface modules and a communication network. The plurality of interface modules are coupled to the power source by way of the power transmission link and are interconnected to each other by way of the communication network. Each of the plurality of interface modules is coupled to respective ones of the plurality of input devices and the plurality of output devices by way of respective dedicated communication links. The on-board computer system stores I/O status information for the plurality of input devices and the plurality of output devices. The on-board computer system transmits at least some of the I/O status information by way of a wireless radio-frequency communication link to the off-board computer system.

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EQUIPMENT SERVICE VEHICLE WITH REMOTE MONITORING

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Prov. No. 60/342,292, filed December 21, 2001, entitled "Vehicle Control and Monitoring System and Method," U.S. Prov. No. 60/360,479, filed February 28, 2002, entitled "Turret Control System and Method for a Fire Fighting Vehicle," and U.S. Prov. No. 60/388,451, filed June 13, 2002, entitled "Control System and Method for an Equipment Service Vehicle."

BACKGROUND OF THE INVENTION

[0002] The present invention relates to equipment service vehicles. The present invention also relates to vehicles that can communicate with a computer system external to the vehicle.

[0003] Modern vehicles have become increasingly complex and difficult to maintain. In order to enable more efficient vehicle maintenance, it is desirable to be able to accurately diagnose malfunctioning subsystems, such as engine systems, transmission systems, and so on, as well as specific vehicle parts or components. When a malfunction is not properly diagnosed, the result is typically that parts which are fully operational are repaired or replaced, that parts which are repairable are replaced, and/or that parts which are not fully operational are not repaired or replaced. Accurate diagnoses therefore allow more efficient vehicle maintenance by avoiding unnecessary repairs and replacements, and by enabling necessary repairs and replacements to be made.

[0004] Co-pending application Serial No. 09/500,506 discloses a network-based on-board diagnostic system capable of performing diagnostic tests to assess vehicle operational readiness and, if a problem exists, to quickly fault isolate to a replaceable item. This system offers numerous advantages, for example, this system makes it possible to diagnose vehicle malfunctions without necessarily bringing the vehicle to a maintenance depot. Indeed, the services offered by this system are available wherever and whenever the vehicle is in operation.

[0005] However, once a vehicle problem is diagnosed, there remains the potential that the vehicle may be out of service for an extended period of time. Many times the part is unique to the specific equipment service vehicle and must be ordered directly from the manufacturer. It would be desirable simplify the process of ordering replacement parts once a vehicle problem has been diagnosed.

[0006] In addition to replacing and repairing parts, equipment service vehicles often have routine and preventative maintenance performed at regular intervals. In many instances, routine maintenance is only scheduled if the operator notices that.it is time for the maintenance. However, operators may be busy with other duties and forget to schedule the equipment service vehicle for maintenance. Accordingly, it would be advantageous to have an equipment service vehicle that can schedule routine maintenance with little or no input from the operator or other person responsible for maintaining the vehicle.

[0007] In addition to routine maintenance, equipment service vehicles may be the subjects of a recall. Currently, communicating recall information to the owners of equipment service vehicles is typically done using sales records and general advertisements. However, these methods may not reach those owners that purchased the vehicle used or have moved to a new location since the original sale. In many recall situations, the number of owners that do not receive the recall information or do not act on the information once it is received is substantial. Accordingly, it would be advantageous to communicate the recall information to a computer on the equipment service vehicle that may inform the owner of the recall and may even automatically set up a service appointment to comply with the recall.

[0008] Even in situations where servicing of a vehicle is not needed, it is often desirable to be able to assess and monitor vehicle performance from remote locations. For example, in the context of a fleet of vehicles, it is sometimes desirable to be able to quickly and easily obtain information about the fleet of vehicles without necessarily having to bring the vehicle into a service depot.

[0009] There is an ongoing need for equipment service vehicles and related method and systems that make maintaining and servicing the vehicle simpler and easier. Decreasing the amount of time spent on service and repair of the vehicle decreases the costs associated with maintaining and owning the vehicle. There is also an

ongoing need for methods and systems that facilitate assessing and monitoring vehicle performance from remote locations.

SUMMARY OF THE INVENTION

[0010] According to a first preferred embodiment, a system comprises an equipment service vehicle and an off-board computer system. The equipment service vehicle further includes a power source, a power transmission link, a plurality of input devices, a plurality of output devices, and an on-board computer system. The on-board computer system further includes a plurality of microprocessor-based interface modules and a communication network. The plurality of interface modules are coupled to the power source by way of the power transmission link and are interconnected to each other by way of the communication network. Each of the plurality of interface modules is coupled to respective ones of the plurality of input devices and the plurality of output devices by way of respective dedicated communication links. The on-board computer system stores I/O status information for the plurality of input devices and the plurality of output devices. The on-board computer system transmits at least some of the I/O status information by way of a wireless radio-frequency communication link to the off-board computer system.

[0011] According to a second preferred embodiment, a system comprises an equipment service vehicle including a power source, a power transmission link, a plurality of input devices, a plurality of output devices, a communication network, and an on-board computer system including a plurality of microprocessor-based interface modules. The plurality of interface modules are coupled to the power source by way of the power transmission link and are interconnected to each other by way of the communication network. Each of the plurality of interface modules is coupled to respective ones of the plurality of input devices and the plurality of output devices by way of respective dedicated communication links. The off-board computer system transmits test commands to the on-board computer system by way of a wireless radio-frequency communication link. The on-board computer system performs tests on the vehicle in response to the test commands from the off-board computer system. The on-board computer system receives the health and operation information in response to the tests being performed. The health and operation information indicates that the equipment service vehicle has a part in need of replacing. The on-board

communication transmits the health and operation information to the off-board computer system by way of the wireless radio-frequency communication link.

[0012] According to a third preferred embodiment, a system comprises a fleet of equipment service vehicles and an off-board computer system. Each vehicle in the fleet of vehicles comprises a power source, a power transmission link, a plurality of input devices, a plurality of output devices, and an on-board computer system including a plurality of microprocessor-based interface modules and a communication network. The plurality of interface modules are coupled to the power source by way of the power transmission link. The plurality of interface modules are interconnected to each other by way of the communication network. Each of the plurality of interface modules is coupled to respective ones of the plurality of input devices and the plurality of output devices by way of respective dedicated communication links. The on-board computer system stores I/O status information for the plurality of input devices and the plurality of output devices. The off-board computer system is capable of being connected to each vehicle in the fleet of vehicles by way of a wireless radio-frequency communication network and is also capable of generating a report that compares utilization information for each of the plurality of vehicles.

[0013] According to a fourth preferred embodiment, a system comprises a fleet of vehicles and an off-board computer system. Each vehicle in the fleet of vehicles comprises a power source, a power transmission link, a plurality of input devices, a plurality of output devices, and an on-board computer system including a plurality of microprocessor-based interface modules and a communication network. The plurality of interface modules is coupled to the power source by way of the power transmission link and is . The plurality of interface modules being interconnected to each other by way of the communication network and is coupled to respective ones of the plurality of input devices and the plurality of output devices by way of respective dedicated communication links. The on-board computer system storing I/O status information for the plurality of input devices and the plurality of output devices. The off-board computer system is capable of being connected to each vehicle in the fleet of vehicles by way of a wireless radio-frequency communication network and is capable of sending commands to the on-board computer system of each of the vehicles to test output devices of the equipment service vehicle by manipulating output devices on the equipment service vehicle.

[0014] Other objects, features, and advantages of the present invention will become apparent to those skilled in the art from the following detailed description and accompanying drawings. It should be understood, however, that the detailed description and specific examples, while indicating preferred embodiments of the present invention, are given by way of illustration and not limitation. Many modifications and changes within the scope of the present invention may be made without departing from the spirit thereof, and the invention includes all such modifications.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] Fig. 1 is a schematic view of a fire truck having a control system according to one embodiment of the present invention;

[0016] Fig. 2 is a block diagram of the control system of Fig. 1 showing selected aspects of the control system in greater detail;

[0017] Fig. 3 is a schematic view of a military vehicle having a control system according to another embodiment of the present invention;

[0018] Figs. 4-5 are block diagrams of the control system of Fig. 3 showing selected aspects of the control system in greater detail;

[0019] Figs. 6A-6B are modified views of the block diagram of Fig. 5 showing the operation of the control system to reconfigure itself in a failure mode of operation;

[0020] Fig. 7 is a diagram showing the memory contents of an exemplary interface module in greater detail;

[0021] Fig. 8 is an overview of a preferred variant vehicle system;

[0022] Fig. 9 is a block diagram of the control system of Fig. 3 showing selected aspects of the control system in greater detail;

[0023] Fig. 10 is an I/O status table of Fig. 9 shown in greater detail;

[0024] Fig. 11 is a flowchart describing the operation of the control system of Fig. 9 in greater detail;

[0025] Fig. 12 is a data flow diagram describing data flow through an exemplary interface module during the process of Fig. 11;

[0026] Fig. 13 is a schematic view of a military vehicle having a diagnostic system according to one embodiment of the present invention;

[0027] Fig. 14 is a block diagram of the diagnostic system of Fig. 13 showing selected aspects of the diagnostic system in greater detail;

[0028] Fig. 15 is a menu displayed by a display of the diagnostic system of Fig. 13 showing various services offered by the diagnostic system;

[0029] Fig. 16 is a flow chart showing the operation of the diagnostic system of Fig. 13 to perform a diagnostic test procedure;

[0030] Fig. 17 is a schematic view of a firefighting vehicle having a diagnostic system in accordance with Figs. 13-16;

[0031] Fig. 18 is a schematic view of a mixing vehicle having a diagnostic system in accordance with Figs. 13-16;

[0032] Fig. 19 is a schematic view of a refuse handling vehicle having a diagnostic system in accordance with Figs. 13-16;

[0033] Fig. 20 is a schematic view of a snow removal vehicle having a diagnostic system in accordance with Figs. 13-16;

[0034] Fig. 21 is a schematic view of vehicle maintenance, monitoring, parts ordering, readiness assessment, and deployment system according to another embodiment of the present invention;

[0035] Fig. 22 is a flowchart showing the operation of an on-board vehicle computer system in the system of Fig. 21 during a parts ordering process;

[0036] Fig. 23 is a flowchart showing the operation of a maintenance center computer system in the system of Fig. 21 during a parts ordering process;

[0037] Fig. 24 is another flowchart showing the operation of an on-board computer system in the system of Fig. 21 during a parts ordering process;

[0038] Fig. 25 is a flowchart showing the operation of a maintenance center computer system in the system of Fig. 21 during a readiness assessment process;

[0039] Fig. 26 is a flowchart showing the operation of an on-board vehicle computer system in the system of Fig. 21 during a readiness assessment;

[0040] Fig. 27 is a flowchart showing the operation of the system of Fig. 21 to detect non-conformance to a predetermined route; and

[0041] Figs. 28-38 are various examples of screen display for real time remote monitoring of vehicle I/O status information.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0042] Patent application Ser. Nos. 09/364,690; 09/384,393; 09/927,946; and 60/342,292, disclose various embodiments of control system architectures in connection with fire trucks, military vehicles, electric vehicles and other types of vehicles and combinations thereof. An advantageous use of a control system of the type disclosed is for service, repair, monitoring, parts ordering, and similar features. For such uses, the control systems described in the above-mentioned applications may be used to control additional output devices associated with the vehicle, and to provide I/O status information which may be transmitted off-board the vehicle, and so on, as described below. For convenience, portions of the above-mentioned applications is repeated below, followed by a description of service, repair, and monitoring applications which in a preferred embodiment use a control system of a type disclosed in the above-mentioned applications but which could also use other vehicle-based computer systems.

A. Fire Truck Control System

[0043] Referring now to Fig. 1, a preferred embodiment of a fire truck 10 having a control system 12 is illustrated. By way of overview, the control system 12 comprises a central control unit 14, a plurality of microprocessor-based interface modules 20 and 30, a plurality of input devices 40 and a plurality of output devices 50. The central control unit 14 and the interface modules 20 and 30 are connected to each other by a communication network 60.

[0044] More specifically, the central control unit 14 is a microprocessor-based device and includes a microprocessor 15 that executes a control program 16 (see Fig. 2) stored in memory of the central control unit 14. In general, the control unit 14 executes the program to collect and store input status information from the input devices 40, and to control the output devices 50 based on the collected status information. The control program may implement an interlock system, a load manager, and a load sequencer. As described below, the central control unit 14 is preferably not connected to the I/O devices 40 and 50 directly but rather only indirectly by way of the interface modules 20 and 30, thereby enabling distributed data collection and power distribution. The I/O devices 40 and 50 are located on a chassis 11 of the fire truck 10, which includes both the body and the underbody of the fire truck 10.

[0045] In the illustrated embodiment, two different types of interface modules are used. The interface modules 20 interface mainly with switches and low power indicators, such as LEDs that are integrally fabricated with a particular switch and that are used to provide visual feedback to an operator regarding the state of the particular switch. For this reason, the interface modules 20 are sometimes referred to herein as "SIMs" ("switch interface modules"). Herein, the reference numeral "20" is used to refer to the interface modules 20 collectively, whereas the reference numerals 21, 22 and 23 are used to refer to specific ones of the interface modules 20.

[0046] The interface modules 30 interface with the remaining I/O devices 40 and 50 on the vehicle that do not interface to the interface modules 20, and therefore are sometimes referred to herein as "VIMs" ("vehicle interface modules"). The interface modules 30 are distinguishable from the interface modules 20 mainly in that the interface modules 30 are capable of handling both analog and digital inputs and outputs, and in that they are capable of providing more output power to drive devices such as gauges, valves, solenoids, vehicle lighting and so on. The analog outputs may be true analog outputs or they may be pulse width modulation outputs that are used to emulate analog outputs. Herein, the reference numeral "30" is used to refer to the interface modules 30 collectively, whereas the reference numerals 31, 32, 33, 34 and 35 are used to refer to specific ones of the interface modules 30.

[0047] Although two different types of interface modules are used in the illustrated embodiment, depending on the application, it may be desirable to use only a single

type of interface module in order to reduce inventory requirements. Additionally, while in Fig. 1 three of the interface modules 20 and five of the interface modules 30 are shown, this arrangement is again simply one example. It may be desirable to provide each interface module with more I/O points in order to reduce the number of interface modules that are required, or to use more interface modules with a smaller number of I/O points in order to make the control system 12 more highly distributed. Of course, the number of interface modules will also be affected by the total number of I/O points in the control system.

[0048] Figure 1 shows an approximate distribution of the interface modules 20 and 30 throughout the fire truck 10. In general, in order to minimize wiring, the interface modules 20 and 30 are placed so as to be located as closely as possible to the input devices 40 from which input status information is received and the output devices 50 that are controlled. As shown in Fig. 1, there is a large concentration of interface modules 20 and 30 near the front of the fire truck 10, with an additional interface module 34 at mid-length of the fire truck 10 and another interface module 35 at the rear of the fire truck 10. The large concentration of interface modules 20 and 30 at the front of the fire truck 10 is caused by the large number of switches (including those with integral LED feedback output devices) located in a cab of the fire truck 10, as well as the large number of other output devices (gauges, lighting) which tend to be located in the cab or otherwise near the front of the fire truck 10. The interface module 34 that is located in the middle of the truck is used in connection with I/O devices 40 and 50 that are located at the fire truck pump panel (i.e., the operator panel that has I/O devices for operator control of the fire truck's pump system). The interface module 35 that is located at the rear of the fire truck 10 is used in connection with lighting and other equipment at the rear of the fire truck 10.

[0049] The advantage of distributing the interface modules 20 and 30 in this manner can be more fully appreciated with reference to Fig. 2, which shows the interconnection of the interface modules 20 and 30. As shown in Fig. 2, the interface modules 20 and 30 receive power from a power source 100 by way of a power transmission link 103. The power transmission link 103 may comprise for example a single power line that is routed throughout the fire truck 10 to each of the interface modules 20 and 30. The interface modules then distribute the power to the output

devices 50, which are more specifically designated with the reference numbers 51a, 52a, 53a, 54a-c, 55a-c, 56a-b, 57a-c and 58a-d in Fig. 2.

[0050] It is therefore seen from Figs. 1 and 2 that the relative distribution of the interface modules 20 and 30 throughout the fire truck 10 in combination with the arrangement of the power transmission link 103 allows the amount of wiring on the fire truck 10 to be dramatically reduced. The power source 100 delivers power to the interface modules 20 and 30, which act among other things as power distribution centers, and not directly to the output devices 50. Because the interface modules 20 and 30 are located so closely to the I/O devices 40 and 50, most of the I/O devices can be connected to the interface modules 20 and 30 using only a few feet of wire or less. This eliminates the need for a wire harness that extends the length of the fire truck (about forty feet) to establish connections for each I/O devices 40 and 50 individually.

[0051] Continuing to refer to Fig. 2, the switch interface modules 20 and the interconnection of the interface modules 20 with various I/O devices will now be described in greater detail. The interface modules 20 are microprocessor-based, as previously noted, and include a microprocessor that executes a program to enable communication over the communication network 60, as detailed below.

[0052] The same or a different microprocessor of the interface modules 20 may also be used to process input signals received from the input devices 40. In particular, the interface modules 20 preferably perform debounce filtering of the switch inputs, so as to require that the position of the switch become mechanically stable before a switch transition is reported to the central control unit 14. For example, a delay of fifty milliseconds may be required before a switch transition is reported. Performing this filtering at the interface modules 20 reduces the amount of processing that is required by the central control unit 14 to interpret switch inputs, and also reduces the amount of communication that is required over the communication network 60 because each switch transition need not be reported.

[0053] Physically, the interface modules 20 may be placed near the headliner of a cab 17 of the fire truck 10. Traditionally, it is common practice to locate panels of switches along the headliner of the cab for easy access by an operator of the fire truck. Additionally, as detailed below, in the preferred embodiment, the interface

modules 20 are connected to switches that have integrally fabricated LEDs for indicating the state of the output device controlled by the switch to provide maximum operator feedback. These LEDs are output devices which are connected to the interface modules 20. Therefore, by locating the interface modules near the headliner of the cab, the amount of wiring required to connect the interface modules 20 not only to the switches and but also to the LED indicators is reduced.

[0054] In the preferred embodiment, the interface modules 20 have between ten and twenty-five each of inputs and outputs and, more preferably, have sixteen digital (on/off switch) inputs and sixteen LED outputs. Most of these inputs and outputs are utilized in connection with switches having integrally fabricated LEDs. However, it should be noted that there need not be a one-to-one correspondence between the switches and the LEDs, and that the inputs and the outputs of the interface modules 20 need not be in matched pairs. For example, some inputs may be digital sensors (without a corresponding output device) and some of the outputs may be ordinary digital indicators (without a corresponding input device). Additionally, the LED indicators associated with the switch inputs for the interface module 21 could just as easily be driven by the interface module 23 as by the interface module 21, although this arrangement is not preferred. Of course, it is not necessary that all of the inputs and outputs on a given interface module 20 be utilized and, in fact, it is likely that some will remain unutilized.

[0055] One way of establishing a dedicated link between the I/O devices 40 and 50 and the interface modules 20 is through the use of a simple hardwired link. Considering for example an input device which is a switch, one terminal of the switch may be connected (e.g., by way of a harness connector) to an input terminal of the interface module 20 and the other terminal of the switch may be tied high (bus voltage) or low (ground). Likewise, for an output device which is an LED, one terminal of the LED may be connected to an output terminal of the interface module 20 and the other terminal of the LED may again be tied high or low. Other dedicated links, such as RF links, could also be used.

[0056] To provide maximum operator feedback, the LEDs that are located with the switches have three states, namely, off, on, and blinking. The off state indicates that the switch is off and therefore that the device controlled by the switch is off. Conversely, the on state indicates that the switch is on and that the device controlled

by the switch is on. The blinking state indicates that the control system 12 recognizes that a switch is on, but that the device which the switch controls is nevertheless off for some other reason (e.g., due to the failure of an interlock condition, or due to the operation of the load manager or load sequencer). Notably, the blinking LED feedback is made possible by the fact that the LEDs are controlled by the control unit 14 and not directly by the switches themselves, since the switches themselves do not necessarily know the output state of the devices they control.

[0057] Fig. 2 depicts one example of interconnection of input devices 40 (including input devices 41a, 41b, 42a, 42b, 43a, 43b, 44a, 45a, 46a, 46b, 47a, and 48a) and output devices 50 (including output devices 51a, 52a, 53a, 54a, 54b, 54c, 55a, 55b, 55c, 56a, 56b, 57a, 57b, 57c, 58a, 58b, 58c, 58d) to interface modules 20 and 30 (including interface modules 21, 22, 23, 31, 32, 33, 34 and 35). Many or all of the I/O devices 40 and 50 could be the same as those that have previously been used on fire trucks. Additionally, it should be noted that the example in Fig. 2 is just one example, and that a virtually unlimited number of configurations are possible.

[0058] Like the interface modules 20, the interface modules 30 are microprocessor-based and include a microprocessor that executes a program to enable communication over the communication network 60. The same or a different microprocessor of the interface modules 30 may also be used to process input signals received from the input devices 40 and to process output signals transmitted to the output devices 50. For the interface modules 30, this processing includes not only debounce filtering, in the case of switch inputs, but also a variety of other types of processing. For example, for analog inputs, this processing includes any processing that is required to interpret the inputs from analog-to-digital (A/D) converters, including converting units. For frequency inputs, this processing includes any processing that is required to interpret inputs from frequency-to-digital converters, including converting units. This processing also includes other simple filtering operations. For example, in connection with one analog input, this processing may include notifying the central control unit 14 of the status of an input device only every second or so. In connection with another analog input, this processing may include advising the central control unit 14 only when the status of the input device changes by a predetermined amount. For analog output devices, this processing includes any processing that is required to interpret the outputs for digital-to-analog (D/A) converters, including converting units.

For digital output devices that blink or flash, this processing includes implementing the blinking or flashing (i.e., turning the output device on and off at a predetermined frequency) based on an instruction from the central control unit 14 that the output device should blink or flash. In general, the processing by the interface modules 30 reduces the amount of information which must be communicated over the communication link, and also reduces the amount of time that the central control unit 14 must spend processing minor changes in analog input status.

[0059] Preferably, the configuration information required to implement the I/O processing that has just been described is downloaded from the central control unit 14 to each interface module 30 (and each interface module 20) at power-up. Additionally, the harness connector that connects to each of the interface modules 20 and 30 are preferably electronically keyed, such that being connected to a particular harness connector provides the interface modules 20 and 30 with a unique identification code (for example, by tying various connector pins high and low to implement a binary code). The advantage of this approach is that the interface modules 20 and 30 become interchangeable devices that are customized only at power-up. As a result, if one of the interface modules 30 malfunctions, for example, a new interface module 30 can be plugged into the control system 12, customized automatically at power-up (without user involvement), and the control system 12 then becomes fully operational. This enhances the maintainability of the control system 12.

[0060] The interface modules 20 and the interface modules 30 are connected to the central control unit 14 by the communication network 60. The communication network may be implemented using a network protocol, for example, which is in compliance with the Society of Automotive Engineers (SAE) J1708/1587 and/or J1939 standards. The particular network protocol that is utilized is not critical, although all of the devices on the network should be able to communicate effectively and reliably.

[0061] The transmission medium may be implemented using copper or fiber optic cable. Fiber optic cable is particularly advantageous in connection with fire trucks because fiber optic cable is substantially immune to electromagnetic interference, for example, from communication antennae on mobile news vehicles, which are common at the scenes of fires. Additionally, fiber optic cable is advantageous because it reduces RF

emissions and the possibility of short circuits as compared to copper-based networks. Finally, fiber optic cable is advantageous because it reduces the possibility of electrocution as compared to copper in the event that the cable accidentally comes into contact with power lines at the scene of a fire.

[0062] Also connected to the communication network 60 are a plurality of displays 81 and 82. The displays 81 and 82 permit any of the data collected by the central control unit 14 to be displayed to the firefighters in real time. In practice, the data displayed by the displays 81 and 82 may be displayed in the form of text messages and may be organized into screens of data (given that there is too much data to display at one time) and the displays 81 and 82 may include membrane pushbuttons that allow the firefighters to scroll through, page through, or otherwise view the screens of data that are available. Additionally, although the displays 81 and 82 are both capable of displaying any of the information collected by the central control unit 14, in practice, the displays 81 and 82 are likely to be used only to display selected categories of information. For example, assuming the display 81 is located in the cab and the display 82 is located at the pump panel, the display 81 is likely to be used to display information that pertains to devices which are controlled from within the cab, whereas the display 82 is likely to be used to display information pertaining to the operation of the pump panel. Advantageously, the displays 81 and 82 give firefighters instant access to fire truck information at a single location, which facilitates both normal operations of the fire truck as well as troubleshooting if problems arise.

[0063] Also shown in Fig. 2 is a personal computer 85 which is connected to the control unit 14 by way of a communication link 86, which may be a modem link, an RS-232 link, an Internet link, and so on. The personal computer 85 allows diagnostic software to be utilized for remote or local troubleshooting of the control system 12, for example, through direct examination of inputs, direct control of outputs, and viewing and controlling internal states, including interlock states. Because all I/O status information is stored in the central control unit 14, this information can be easily accessed and manipulated by the personal computer 85. If a problem is encountered, the personal computer can be used to determine whether the central control unit 14 considers all of the interface modules 20 and 30 to be "on-line" and, if not, the operator can check for bad connections and so on. If a particular output

device is not working properly, the personal computer 85 can be used to trace the I/O status information from the switch or other input device through to the malfunctioning output device. For example, the personal computer 85 can be used to determine whether the switch state is being read properly, whether all interlock conditions are met, and so on.

[0064] The personal computer 85 also allows new firmware to be downloaded to the control unit 14 remotely (e.g., from a different city or state or other remote location by way of the Internet or a telephone link) by way of the communication link 86. The firmware can be firmware for the control unit 14, or it can be firmware for the interface modules 20 and 30 that is downloaded to the control unit 14 and then transmitted to the interface modules 20 and 30 by way of the communication network 60.

[0065] Finally, referring back to Fig. 1, several additional systems are shown which will now be briefly described before proceeding to a discussion of the operation of the control system 12. In particular, Fig. 1 shows an engine system including an engine 92 and an engine control system 91, a transmission system including a transmission 93 and a transmission control system 94, and an anti-lock brake system including an anti-lock brake control system 95 and anti-lock brakes 96. The transmission 93 is mechanically coupled to the engine 92, and is itself further mechanically coupled to a PTO system 97. The PTO system 97 allows mechanical power from the engine to be diverted to water pumps, aerial drive mechanisms, stabilizer drive mechanisms, and so on. In combination, the engine system, the transmission system and the PTO system form the power train of the fire truck 10.

[0066] The control systems 92, 94 and 95 may be connected to the central control unit 14 using the same or a different communication network than is used by the interface modules 30 and 40. In practice, the control systems 92, 94 and 95 are likely to be purchased as off-the-shelf systems, since most fire truck manufacturers purchase rather than manufacture engine systems, transmission systems and anti-lock brake systems. As a result, it is likely that the control systems 92, 94 and 95 will use a variety of different communication protocols and therefore that at least one additional communication network will be required.

[0067] By connecting the systems 92, 94 and 95 to the central control unit 14, an array of additional input status information becomes available to the control system 12. For example, for the engine, this allows the central control unit 14 to obtain I/O status information pertaining to engine speed, engine hours, oil temperature, oil pressure, oil level, coolant level, fuel level, and so on. For the transmission, this allows the central control unit 14 to obtain, for example, information pertaining transmission temperature, transmission fluid level and/or transmission state (1st gear, 2nd gear, and so on). Assuming that an off-the-shelf engine or transmission system is used, the information that is available depends on the manufacturer of the system and the information that they have chosen to make available.

[0068] Connecting the systems 92, 94 and 95 to the central control unit 14 is advantageous because it allows information from these subsystems to be displayed to firefighters using the displays 81 and 82. This also allows the central control unit 14 to implement various interlock conditions as a function of the state of the transmission, engine or brake systems. For example, in order to turn on the pump system (which is mechanically driven by the engine and the transmission), an interlock condition may be implemented that requires that the transmission be in neutral or 4th lockup (i.e., fourth gear with the torque converter locked up), so that the pump can only be engaged when the wheels are disengaged from the power train. The status information from these systems can therefore be treated in the same manner as I/O status information from any other discrete I/O device on the fire truck 10. It may also be desirable to provide the central control unit 14 with a limited degree of control over the engine and transmission systems, for example, enabling the central control unit 14 to issue throttle command requests to the engine control system 91. This allows the central control unit to control the speed of the engine and therefore the voltage developed across the alternator that forms part of the power source 100.

[0069] From the foregoing description, a number advantages of the preferred fire truck control system are apparent. In general, the control system is easier to use, more flexible, more robust, and more reliable than existing fire truck control systems. In addition, because of these advantages, the control system also increases firefighter safety because the many of the functions that were previously performed by firefighters are performed automatically, and the control system also makes possible features that

would otherwise be impossible or at least impractical. Therefore, firefighters are freed to focus on fighting fires.

[0070] The control system is easier to use because the control system provides a high level of cooperation between various vehicle subsystems. The control system can keep track of the mode of operation of the fire truck, and can control output devices based on the mode of operation. The functions that are performed on the fire truck are more fully integrated to provide a seamless control system, resulting in better performance.

[0071] For example, features such as load management and load sequencing are implemented in the control program executed by the central control unit. No additional hardware is required to implement load management and load sequencing. Therefore, if it is desired to change the order of load sequencing, all that is required is to modify the control program. It is also possible to have different load sequencing defined for different modes of operation of the vehicle with little or no increase in hardware. The manner in which load management is performed can also be changed dynamically during the operation of the fire truck.

[0072] The control system is robust and can accept almost any new feature without changes in wiring. Switches are connected to a central control unit and not to outputs directly, and new features can be programmed into the control program executed by the central control unit. A system can be modified by adding a new switch to an existing interface module, or by modifying the function of an existing switch in the control program. Therefore, modifying a system that is already in use is easy because little or no wiring changes are required.

[0073] Additionally, because the control system has access to input status information from most or all of the input devices on the fire truck and has control over most or all of the output devices on the fire truck, a high level of cooperation between the various subsystems on the fire truck is possible. Features that require the cooperation of multiple subsystems are much easier to implement.

[0074] The fire truck is also easier to operate because there is improved operator feedback. Displays are provided which can be used to determine the I/O status of any piece of equipment on the vehicle, regardless of the location of the display. Additionally, the displays facilitate troubleshooting, because troubleshooting can be

performed in real time at the scene of a fire when a problem is occurring. Troubleshooting is also facilitated by the fact that the displays are useable to display all of the I/O status information on the fire truck. There is no need for a firefighter to go to different locations on the fire truck to obtain required information. Troubleshooting is also facilitated by the provision of a central control unit which can be connected by modem to another computer. This allows the manufacturer to troubleshoot the fire truck as soon as problems arise.

[0075] LED indicators associated with switches also improve operator feedback. The LEDs indicate whether the switch is considered to be off or on, or whether the switch is considered to be on but the output device controlled by the switch is nevertheless off due to some other condition on the fire truck.

[0076] Because the control system is easier to use, firefighter safety is enhanced. When a firefighter is fighting fires, the firefighter is able to more fully concentrate on fighting the fire and less on having to worry about the fire truck. To the extent that the control system accomplishes tasks that otherwise would have to be performed by the firefighter, this frees the firefighter to fight fires.

[0077] The control system is also more reliable and maintainable, in part because relay logic is replaced with logic implemented in a control program. The logic in the control program is much easier to troubleshoot, and troubleshooting can even occur remotely by modem. Also mechanical circuit breakers can be replaced with electronic control, thereby further reducing the number of mechanical failure points and making current control occur more seamlessly. The simplicity of the control system minimizes the number of potential failure points and therefore enhances reliability and maintainability.

[0078] The system is also more reliable and more maintainable because there is less wire. Wiring is utilized only to established dedicated links between input/output devices and the interface module to which they are connected. The control system uses distributed power distribution and data collecting. The interface modules are interconnected by a network communication link instead of a hardwired link, thereby reducing the amount of wiring on the fire truck. Most wiring is localized wiring between the I/O devices and a particular interface module.

[0079] Additionally, the interface modules are interchangeable units. In the disclosed embodiment, the interface modules 20 are interchangeable with each other, and the interface modules 30 are interchangeable with each other. If a greater degree of interchangeability is required, it is also possible to use only a single type of interface module. If the control system were also applied to other types of equipment service vehicles (e.g., snow removal vehicles, refuse handling vehicles, cement/concrete mixers, military vehicles such as those of the multipurpose modular type, on/off road severe duty equipment service vehicles, and so on), the interface modules would even be made interchangeable across platforms since each interface module views the outside world in terms of generic inputs and outputs, at least until configured by the central control unit. Because the interface modules are interchangeable, maintainability is enhanced. An interface module that begins to malfunction due to component defects may be replaced more easily. On power up, the central control unit downloads configuration information to the new interface module, and the interface module becomes fully operational. This enhances the maintainability of the control system.

[0080] Because the interface modules are microprocessor-based, the amount of processing required by the central control unit as well as the amount of communication that is necessary between the interface modules and the central control unit is reduced. The interface modules perform preprocessing of input signals and filter out less critical input signals and, as a result, the central control unit receives and responds to critical messages more quickly.

B. Military Vehicle Control System

[0081] Referring now to Fig. 3, a preferred embodiment of a military vehicle 1410 having a control system 1412 is illustrated. As previously indicated, the control system described above can be applied to other types of equipment service vehicles, such as military vehicles, because the interface modules view the outside world in terms of generic inputs and outputs. Most or all of the advantages described above in the context of fire fighting vehicles are also applicable to military vehicles. As previously described, however, it is sometimes desirable in the context of military applications for the military vehicle control system to be able to operate at a maximum level of effectiveness when the vehicle is damaged by enemy fire, nearby explosions, and so on. In this situation, the control system 1412 preferably incorporates a number of

additional features, discussed below, that increase the effectiveness of the control system 1412 in these military applications.

[0082] By way of overview, the control system 1412 comprises a plurality of microprocessor-based interface modules 1420, a plurality of input and output devices 1440 and 1450 (see Fig. 4) that are connected to the interface modules 1420, and a communication network 1460 that interconnects the interface modules 1420. The control system 1412 preferably operates in the same manner as the control system 12 of Figs. 1-2, except to the extent that differences are outlined are below. A primary difference between the control system 12 and the control system 1412 is that the control system 1412 does not include a central control unit that is implemented by a single device fixed at one location. Rather, the control system 1412 includes a central control unit that is allowed to move from location to location by designating one of the interface modules 1420 as a "master" interface module and by further allowing the particular interface module that is the designated master interface module to change in response to system conditions. As will be detailed below, this feature allows the control system 1412 to operate at a maximum level of effectiveness when the military vehicle 1410 is damaged. Additional features that assist failure management are also included.

[0083] More specifically, in the illustrated embodiment, the control system 1412 is used in connection with a military vehicle 1410 which is a multipurpose modular military vehicle. As is known, a multipurpose module vehicle comprises a chassis and a variant module that is capable of being mounted on the chassis, removed, and replaced with another variant module, thereby allowing the same chassis to be used for different types of vehicles with different types of functionality depending on which variant module is mounted to the chassis. In the illustrated embodiment, the military vehicle 1410 is a wrecker and includes a wrecker variant module 1413 mounted on a chassis (underbody) 1417 of the military vehicle 1410. The weight of the variant module 1413 is supported by the chassis 1417. The variant module 1413 includes a mechanical drive device 1414 capable of imparting motion to solid or liquid matter that is not part of the military vehicle 1410 to provide the military vehicle 1410 with a particular type of functionality. In Fig. 3, where the variant module 1413 is a wrecker variant, the mechanical drive device is capable of imparting motion to a towed vehicle. As shown in Fig. 8, the variant module 1413 is removable and replaceable with other

types of variant modules, which may include a dump truck variant 1418a, a water pump variant 1418b, a telephone variant 1418c, and so on. Thus, for example, the wrecker variant 1413 may be removed and replaced with a water pump variant 1418b having a different type of drive mechanism (a water pump) to provide a different type of functionality (pumper functionality). The I/O devices 1440 and 1450 used by the vehicle 1410 include devices that are the same as or similar to the non-fire truck specific I/O devices of Figs. 1-2 (i.e., those types of I/O devices that are generic to most types of vehicles), as well as I/O devices that are typically found on the specific type of variant module chosen (in Fig. 3, a wrecker variant).

[0084] The interface modules 1420 are constructed in generally the same manner as the interface modules 20 and 30 and each include a plurality of analog and digital inputs and outputs. The number and type of inputs and outputs may be the same, for example, as the vehicle interface modules 30. Preferably, as described in greater detail below, only a single type of interface module is utilized in order to increase the field serviceability of the control system 1412. Herein, the reference numeral 1420 is used to refer to the interface modules 1420 collectively, whereas the reference numerals 1421-1430 are used to refer to specific ones of the interface modules 1420. The interface modules are described in greater detail in connection with Figs. 4-7.

[0085] Also connected to the communication network 1460 are a plurality of displays 1481 and 1482 and a data logger 1485. The displays 1481 and 1482 permit any of the data collected by the control system 1412 to be displayed in real time, and also display warning messages. The displays 1481 and 1482 also include membrane pushbuttons that allow the operators to scroll through, page through, or otherwise view the screens of data that are available. The membrane pushbuttons may also allow operators to change values of parameters in the control system 1412. The data logger 1485 is used to store information regarding the operation of the military vehicle 1410. The data logger 1485 may also be used as a "black box recorder" to store information logged during a predetermined amount of time (e.g., thirty seconds) immediately prior to the occurrence of one or more trigger events (e.g., events indicating that the military vehicle 1410 has been damaged or rendered inoperative, such as when an operational parameter such as an accelerometer threshold has been exceeded).

[0086] Finally, Fig. 3 shows an engine system including an engine 1492 and an engine control system 1491, a transmission system including a transmission 1493 and a transmission control system 1494, and an anti-lock brake system including an anti-lock brake control system 1495. These systems may be interconnected with the control system 1412 in generally the same manner as discussed above in connection with the engine 92, the engine control system 91, the transmission 93, the transmission control system 94, and the anti-lock brake system 36 of Fig. 1.

[0087] Referring now also to Fig. 4-7, the structure and interconnection of the interface modules 1420 is described in greater detail. Referring first to Fig. 4, the interconnection of the interface modules 1420 with a power source 1500 is described. The interface modules 1420 receive power from the power source 1500 by way of a power transmission link 1502. The interface modules 1420 are distributed throughout the military vehicle 1410, with some of the interface modules 1420 being located on the chassis 1417 and some of the interface modules 1420 being located on the variant module 1413.

[0088] The control system is subdivided into three control systems including a chassis control system 1511, a variant control system 1512, and an auxiliary control system 1513. The chassis control system 1511 includes the interface modules 1421-1425 and the I/O devices 1441 and 1451, which are all mounted on the chassis 1417. The variant control system 1512 includes the interface modules 1426-1428 and the I/O devices 1442 and 1452, which are all mounted on the variant module 1413. The auxiliary control system 1513 includes the interface modules 1429-1430 and the I/O devices 1443 and 1453, which may be mounted on either the chassis 1417 or the variant module 1413 or both.

[0089] The auxiliary control system 1513 may, for example, be used to control a subsystem that is disposed on the variant module but that is likely to be the same or similar for all variant modules (e.g., a lighting subsystem that includes headlights, tail lights, brake lights, and blinkers). The inclusion of interface modules 1420 within a particular control system may also be performed based on location rather than functionality. For example, if the variant module 1413 has an aerial device, it may be desirable to have one control system for the chassis, one control system for the aerial device, and one control system for the remainder of the variant module. Additionally, although each interface module 1420 is shown as being associated with only one of

the control systems 1511-1513, it is possible to have interface modules that are associated with more than one control system. It should also be noted that the number of sub-control systems, as well as the number of interface modules, is likely to vary depending on the application. For example, a mobile command vehicle is likely to have more control subsystems than a wrecker variant, given the large number of I/O devices usually found on mobile command vehicles.

[0090] The power transmission link 1502 may comprise a single power line that is routed throughout the military vehicle 1410 to each of the interface modules 1420, but preferably comprises redundant power lines. Again, in order to minimize wiring, the interface modules 1420 are placed so as to be located as closely as possible to the input devices 1440 from which input status information is received and the output devices 1450 that are controlled. This arrangement allows the previously-described advantages associated with distributed data collection and power distribution to be achieved. Dedicated communication links, which may for example be electric or photonic links, connect the interface modules 1421-1430 modules with respective ones of the I/O devices, as previously described.

[0091] Referring next to Fig. 5, the interconnection of the interface modules 1420 by way of the communication network 1460 is illustrated. As previously indicated, the control system 1412 is subdivided into three control systems 1511, 1512 and 1513. In accordance with this arrangement, the communication network 1460 is likewise further subdivided into three communication networks 1661, 1662, and 1663. The communication network 1661 is associated with the chassis control system 1511 and interconnects the interface modules 1421-1425. The communication network 1662 is associated with the variant control system 1512 and interconnects the interface modules 1426-1428. The communication network 1663 is associated with the auxiliary control system 1513 and interconnects the interface modules 1429-1430. Communication between the control systems 1511-1513 occurs by way of interface modules that are connected to multiple ones of the networks 1661-1663. Advantageously, this arrangement also allows the interface modules to reconfigure themselves to communicate over another network in the event that part or all of their primary network is lost. For example, in Fig. 6A, when a portion of the communication network 1663 is lost, the interface module 1429

reconfigures itself to communicate with the interface module 1430 by way of the communication network 1662 and the interface module 1427.

[0092] In practice, each of the communication networks 1661-1663 may be formed of two or more communication networks to provide redundancy within each control system. Indeed, the connection of the various interface modules 1420 with different networks can be as complicated as necessary to obtain the desired level of redundancy. For simplicity, these potential additional levels of redundancy will be ignored in the discussion of Fig. 5 contained herein.

[0093] The communication networks 1661-1663 may be implemented in accordance with SAE J1708/1587 and/or J1939 standards, or some other network protocol, as previously described. The transmission medium is preferably fiber optic cable in order to reduce the amount of electromagnetic radiation that the military vehicle 1410 produces, therefore making the vehicle less detectable by the enemy. Fiber optic networks are also more robust to the extent that a severed fiber optic cable is still usable to create two independent networks, at least with reduced functionality.

[0094] When the variant module 1413 is mounted on the chassis 1417, connecting the chassis control system 1511 and the variant control system 1512 is achieved simply through the use of two mating connectors 1681 and 1682 that include connections for one or more communication busses, power and ground. The chassis connector 1682 is also physically and functionally mateable with connectors for other variant modules, i.e., the chassis connector and the other variant connectors are not only capable of mating physically, but the mating also produces a workable vehicle system. A given set of switches or other control devices 1651 on the dash (see Fig. 3) may then operate differently depending on which variant is connected to the chassis. Advantageously, therefore, it is possible to provide a single interface between the chassis and the variant module (although multiple interfaces may also be provided for redundancy). This avoids the need for a separate connector on the chassis for each different type of variant module, along with the additional unutilized hardware and wiring, as has conventionally been the approach utilized.

[0095] Upon power up, the variant control system 1512 and the chassis control system 1511 exchange information that is of interest to each other. For example, the

variant control system 1512 may communicate the variant type of the variant module 1413. Other parameters may also be communicated. For example, information about the weight distribution on the variant module 1413 may be passed along to the chassis control system 1511, so that the transmission shift schedule of the transmission 1493 can be adjusted in accordance with the weight of the variant module 1413, and so that a central tire inflation system can control the inflation of tires as a function of the weight distribution of the variant. Similarly, information about the chassis can be passed along to the variant. For example, where a variant module is capable of being used by multiple chassis with different engine sizes, engine information can be communicated to a wrecker variant module so that the wrecker variant knows how much weight the chassis is capable of pulling. Thus, an initial exchange of information in this manner allows the operation of the chassis control system 1511 to be optimized in accordance with parameters of the variant module 1413, and vice versa.

[0096] It may also be noted that the advantages obtained for military variants can also be realized in connection with commercial variants. Thus, a blower module, a sweeper module, and a plow module could be provided for the same chassis. This would allow the chassis to be used for a sweeper in summer and a snow blower or snow plow in winter.

[0097] As shown in Fig. 5, each control system 1511-1513 includes an interface module that is designated "master" and another that is designated "deputy master." Thus, for example, the chassis control system 1511 includes a master interface module 1423 and a deputy master interface module 1422. Additional tiers of mastership may also be implemented in connection with the interface modules 1421, 1424 and 1425.

[0098] The interface modules 1420 are assigned their respective ranks in the tiers of mastership based on their respective locations on the military vehicle 1410. A harness connector at each respective location of the military vehicle 1410 connects a respective one of the interface modules 1420 to the remainder of the control system 1412. The harness connector is electronically keyed, such that being connected to a particular harness connector provides an interface module 1420 with a unique identification code or address M. For simplicity, the value M is assumed to be a value

between 1 and N, where N is the total number of interface modules on the vehicle (M = 10 in the illustrated embodiment).

[0099] The interface modules 1420 each store configuration information that, among other things, relates particular network addresses with particular ranks of mastership. Thus, for example, when the interface module 1423 boots up, it ascertains its own network address and, based on its network address, ascertains that it is the master of the control system 1511. The interface module 1423 serves as the central control unit so long as the interface module 1423 is competent to do so. As shown in Fig. 6B, if it is determined that the interface module 1423 is no longer competent to serve as master (e.g., because the interface module 1423 has been damaged in combat), then the interface module 1422 becomes the master interface module and begins serving as the central control unit. This decision can be made, for example, by the interface module 1423 itself, based on a vote taken by the remaining interface modules 1420, or based on a decision by the deputy master.

[0100] Referring next to Fig. 7, an exemplary one of the interface modules 1420 is shown in greater detail. The interface modules 1420 each include a microprocessor 1815 that is sufficiently powerful to allow each interface module to serve as the central control unit. The interface modules are identically programmed and each include a memory 1831 that further includes a program memory 1832 and a data memory 1834. The program memory 1832 includes BIOS (basic input/output system) firmware 1836, an operating system 1838, and application programs 1840, 1842 and 1844. The application programs include a chassis control program 1840, one or more variant control programs 1842, and an auxiliary control program 1844. The data memory 1834 includes configuration information 1846 and I/O status information 1848 for all of the modules 1420-1430 associated with the chassis 1417 and its variant module 1413, as well as configuration information for the interface modules (N+1 to Z in Fig. 7) of other variant modules that are capable of being mounted to the chassis 1417.

[0101] It is therefore seen that all of the interface modules 1420 that are used on the chassis 1417 and its variant module 1413, as well as the interface modules 1420 of other variant modules that are capable of being mounted to the chassis 1417, are identically programmed and contain the same information. Each interface module 1420 then utilizes its network address to decide when booting up which configuration

information to utilize when configuring itself, and which portions of the application programs 1840-1844 to execute given its status as a master or non-master member of one of the control systems 1511-1513. The interface modules are both physically and functionally interchangeable because the interface modules are capable of being plugged in at any slot on the network, and are capable of performing any functions that are required at that slot on the network.

[0102] This arrangement is highly advantageous. Because all of the interface modules 1420 are identically programmed and store the same information, the interface modules are physically and functionally interchangeable within a given class of vehicles. Thus, if an interface module 1420 on one variant module is rendered inoperative, but the variant module is otherwise operational, the inoperative interface module can be replaced with an interface module scavenged from another inoperative vehicle. When the replacement interface module 1420 reboots, it will then reconfigure itself for use in the new vehicle, and begin operating the correct portions of the application programs 1840-1844. This is the case even when the two vehicles are different types of vehicles.

[0103] Additionally, if a highly critical interface module is rendered inoperable, the highly critical interface module can be swapped with an interface module that is less critical. Although the input/output devices associated with the less critical interface module will no longer be operable, the input/output devices associated with the more critical interface module will be operable. This allows the effectiveness of the military vehicle to be maximized by allowing undamaged interface modules to be utilized in the most optimal manner. In this way, the field serviceability of the control system 1412 is dramatically improved. Further, the field serviceability of the control system 1412 is also improved by the fact that only a single type of interface module is used, because the use of a single type of interface module makes it easier to find replacement interface modules.

[0104] Additionally, as previously noted, each interface module 1420 stores I/O status information for all of the modules 1420-1430 associated with the chassis 1417 and its variant module 1413. Therefore, each interface module 1420 has total system awareness. As a result, it is possible to have each interface module 1420 process its own inputs and outputs based on the I/O status information in order to increase system responsiveness and in order to reduce the amount of communication that is

required with the central control unit. The main management responsibility of the central control unit or master interface module above and beyond the responsibilities of all the other interface modules 1420 then becomes, for example, to provide a nexus for interface operations with devices that are external to the control system of which the central control unit is a part.

C. I/O Status Communication

[0105] As previously described, each interface module 1420 has total system awareness and it is possible to have each interface module 1420 process its own inputs and outputs based on the I/O status information in order to increase system responsiveness and in order to reduce the amount of communication that is required. Specifically, the data memory 1834 of each interface module 1420 stores I/O status information 1848 for not only local I/O devices 1440 and 1450 but also for non-local I/O devices 1440 and 1450 connected to remaining ones of the interface modules 1420. Referring now to Figs. 9-12, a preferred technique for transmitting I/O status information between the interface modules 1420 will now be described. Although this technique is primarily described in connection with the chassis control system 1511, this technique is preferably also applied to the variant control system 1512 and the auxiliary control system 1513, and/or in the control system 12.

[0106] Referring first to Fig. 9, as previously described, the chassis control system 1511 includes the interface modules 1421-1425, the input devices 1441, and the output devices 1451. Also shown in Fig. 9 are the display 1481, the data logger 1485, and the communication network 1661 which connects the interface modules 1421-1425. In practice, the system may include additional devices, such as a plurality of switch interface modules connected to additional I/O devices, which for simplicity are not shown. The switch interface modules may be the same as the switch interface modules 20 previously described and, for example, may be provided in the form of a separate enclosed unit or in the more simple form of a circuit board mounted with associated switches and low power output devices. In practice, the system may include other systems, such as a display interface used to drive one or more analog displays (such as gauges) using data received from the communication network 1661. Any additional modules that interface with I/O devices preferably broadcast and receive I/O status information and exert local control in the same manner as detailed below in connection with the interface modules 1421-1425. As

previously noted, one or more additional communication networks may also be included which are preferably implemented in accordance with SAE J1708/1587 and/or J1939 standards. The communication networks may be used, for example, to receive I/O status information from other vehicle systems, such as an engine or transmission control system. Arbitration of I/O status broadcasts between the communication networks can be performed by one of the interface modules 1420.

[0107] To facilitate description, the input devices 1441 and the output devices 1451 have been further subdivided and more specifically labeled in Fig. 9. Thus, the subset of the input devices 1441 which are connected to the interface module 1421 are collectively labeled with the reference numeral 1541 and are individually labeled as having respective input states I-11 to I-15. Similarly, the subset of the output devices 1451 which are connected to the interface module 1421 are collectively labeled with the reference numeral 1551 and are individually labeled as having respective output states O-11 to O-15. A similar pattern has been followed for the interface modules 1422-1425, as summarized in Table I below:

Interface Module	Input Devices	Input States	Output Devices	Output States
1421	1541	I-11 to I-15	1551	O-11 to O-15
1422	1542	I-21 to I-25	1552	O-21 to O-25
1423	1543	I-31 to I-35	1553	O-31 to O-35
1424	1544	I-41 to I-45	1554	O-41 to O-45
1425	1545	I-51 to I-55	1555	O-51 to O-55

Table I

[0108] Of course, although five input devices 1441 and five output devices 1451 are connected to each of the interface modules 1420 in the illustrated embodiment, this number of I/O devices is merely exemplary and a different number of devices could also be used, as previously described.

[0109] The interface modules 1420 each comprise a respective I/O status table 1520 that stores information pertaining to the I/O states of the input and output devices 1441 and 1451. Referring now to Fig. 10, an exemplary one of the I/O status tables 1520 is shown. As shown in Fig. 10, the I/O status table 1520 stores I/O status information pertaining to each of the input states I-11 to I-15, I-21 to I-25, I-31

to I-35, I-41 to I-45, and I-51 to I-55 of the input devices 1541-1545, respectively, and also stores I/O status information pertaining to each of the output states O-11 to O-15, O-21 to O-25, O-31 to O-35, O-41 to O-45, and O-51 to O-55 of the output devices 1551-1555, respectively. The I/O status tables 1520 are assumed to be identical, however, each I/O status table 1520 is individually maintained and updated by the corresponding interface module 1420. Therefore, temporary differences may exist between the I/O status tables 1520 as updated I/O status information is received and stored. Although not shown, the I/O status table 1520 also stores I/O status information for the interface modules 1426-1428 of the variant control system 1512 and the interface modules 1429-1430 of the auxiliary control system 1513.

[0110] In practice, although Fig. 10 shows the I/O status information being stored next to each other, the memory locations that store the I/O status information need not be contiguous and need not be located in the same physical media. It may also be noted that the I/O status table 1520 is, in practice, implemented such that different I/O states are stored using different amounts of memory. For example, some locations store a single bit of information (as in the case of a digital input device or digital output device) and other locations store multiple bits of information (as in the case of an analog input device or an analog output device). The manner in which the I/O status table is implemented is dependent on the programming language used and on the different data structures available within the programming language that is used. In general, the term I/O status table is broadly used herein to encompass any group of memory locations that are useable for storing I/O status information.

[0111] Also shown in Fig. 10 are a plurality of locations that store intermediate status information, labeled IM-11, IM-21, IM-22, and IM-41. The intermediate states IM-11, IM-21, IM-22, and IM-41 are processed versions of selected I/O states. For example, input signals may be processed for purposes of scaling, unit conversion and/or calibration, and it may be useful in some cases to store the processed I/O status information. Alternatively, the intermediate states IM-11, IM-21, IM-22, and IM-41 may be a function of a plurality of I/O states that in combination have some particular significance. The processed I/O status information is then transmitted to the remaining interface modules 1420.

[0112] Referring now to Figs. 11-12, Fig. 11 is a flowchart describing the operation of the control system of Fig. 9, and Fig. 12 is a data flow diagram describing data

flow through an exemplary interface module during the process of Fig. 11. As an initial matter, it should be noted that although Fig. 11 depicts a series of steps which are performed sequentially, the steps shown in Fig. 11 need not be performed in any particular order. In practice, for example, modular programming techniques are used and therefore some of the steps are performed essentially simultaneously. Additionally, it may be noted that the steps shown in Fig. 11 are performed repetitively during the operation of the interface module 1421, and some of the steps are in practice performed more frequently than others. For example, input information is acquired from the input devices more often than the input information is broadcast over the communication network. Although the process of Fig. 11 and the data flow diagram of Fig. 12 are primarily described in connection with the interface module 1421, the remaining interface modules 1422-1425 operate in the same manner.

[0113] At step 1852, the interface module 1421 acquires input status information from the local input devices 1541. The input status information, which pertains to the input states I-11 to I-15 of the input devices 1541, is transmitted from the input devices 1541 to the interface module 1421 by way of respective dedicated communication links. At step 1854, the input status information acquired from the local input devices 1541 is stored in the I/O status table 1520 at a location 1531. For the interface module 1421, the I/O devices 1541 and 1551 are referred to as local I/O devices since the I/O devices 1541 and 1551 are directly coupled to the interface module 1421 by way of respective dedicated communication links, as opposed to the remaining non-local I/O devices and 1542-1545 and 1552-1555 which are indirectly coupled to the interface module 1421 by way of the communication network 1661.

[0114] At step 1856, the interface module 1421 acquires I/O status information for the non-local input devices 1542-1545 and the non-local output devices 1552-1555 by way of the communication network 1661. Specifically, the interface module 1421 acquires input status information pertaining to the input states I-21 to I-25, I-31 to I-35, I-41 to I-45, I-51 to I-55 of the input devices 1542-1545, respectively, and acquires output status information pertaining to the output states O-21 to O-25, O-31 to O-35, O-41 to O-45, O-51 to O-55 of the output devices 1552-1555. The input status information and the output status information are stored in locations 1533 and 1534 of the I/O status table 1520, respectively.

[0115] At step 1860, the interface module 1421 determines desired output states O-11 to O-15 for the output devices 1551. As previously noted, each of the interface modules 1420 stores a chassis control program 1840, one or more variant control programs 1842, and an auxiliary control program 1844. The interface module 1421 is associated with the chassis control system 1511 and, therefore, executes a portion of the chassis control program 1840. (The portion of the chassis control program 1840 executed by the interface module 1421 is determined by the location of the interface module 1421 on the military vehicle 1410, as previously described.) The interface module 1421 executes the chassis control program 1840 to determine the desired output states O-11 to O-15 based on the I/O status information stored in the I/O status table 1520. Preferably, each interface module 1420 has complete control of its local output devices 1450, such that only I/O status information is transmitted on the communication network 1460 between the interface modules 1420.

[0116] At step 1862, the interface module 1421 controls the output devices 1551 in accordance with the desired respective output states O-11 to O-15. Once the desired output state for a particular output device 1551 has been determined, control is achieved by transmitting a control signal to the particular output device 1551 by way of a dedicated communication link. For example, if the output is a digital output device (e.g., a headlight controlled in on/off fashion), then the control signal is provided by providing power to the headlight by way of the dedicated communication link. Ordinarily, the actual output state and the desired output state for a particular output device are the same, especially in the case of digital output devices. However, this is not always the case. For example, if the headlight mentioned above is burned out, the actual output state of the headlight may be "off," even though the desired output state of the light is "on." Alternatively, for an analog output device, the desired and actual output states may be different if the control signal is not properly calibrated for the output device.

[0117] At step 1864, the interface module 1421 stores output status information pertaining to the desired output states O-11 to O-15 for the output devices 1551 in the I/O status table 1520. This allows the output states O-11 to O-15 to be stored prior to being broadcast on the communication network 1661. At step 1866, the interface module 1421 broadcasts the input status information pertaining to the input states I-11 to I-15 of the input devices 1541 and the output status information

pertaining to the output states O-11 to O-15 of the output devices 1551 over the communication network 1661. The I/O status information is received by the interface modules 1422-1425. Step 1866 is essentially the opposite of step 1856, in which non-local I/O status information is acquired by the interface module 1421 by way of the communication network 1661. In other words, each interface module 1420 broadcasts its portion of the I/O status table 1520 on the communication network 1661, and monitors the communication network 1661 for broadcasts from the remaining interface modules 1420 to update the I/O status table 1520 to reflect updated I/O states for the non-local I/O devices 1441 and 1451. In this way, each interface module 1420 is able to maintain a complete copy of the I/O status information for all of the I/O devices 1441 and 1451 in the system.

[0118] The interface modules 1423 and 1425 are used to transmit I/O status information between the various control systems 1511-1513. Specifically, as previously noted, the interface module 1423 is connected to both the communication network 1661 for the chassis control system 1511 and to the communication network 1662 for the variant control system 1512 (see Fig. 5). The interface module 1423 is preferably utilized to relay broadcasts of I/O status information back and forth between the interface modules 1421-1425 of the chassis control system 1511 and the interface modules 1426-1428 of the variant control system 1512. Similarly, the interface module 1425 is connected to both the communication network 1661 for the chassis control system 1511 and the to the communication network 1663 for the auxiliary control system 1513 (see Fig. 5), and the interface module 1425 is preferably utilized to relay broadcasts of I/O status information back and forth between the interface modules 1421-1425 of the chassis control system 1511 and the interface modules 1429-1430 of the auxiliary control system 1513.

[0119] The arrangement of Figs. 9-12 is advantageous because it provides a fast and efficient mechanism for updating the I/O status information 1848 stored in the data memory 1834 of each of the interface modules 1420. Each interface module 1420 automatically receives, at regular intervals, complete I/O status updates from each of the remaining interface modules 1420. There is no need to transmit data request (polling) messages and data response messages (both of which require communication overhead) to communicate information pertaining to individual I/O states between individual I/O modules 1420. Although more I/O status data is

transmitted, the transmissions require less overhead and therefore the overall communication bandwidth required is reduced.

[0120] This arrangement also increases system responsiveness. First, system responsiveness is improved because each interface module 1420 receives current I/O status information automatically, before the information is actually needed. When it is determined that a particular piece of I/O status information is needed, there is no need to request that information from another interface module 1420 and subsequently wait for the information to arrive via the communication network 1661. The most current I/O status information is already assumed to be stored in the local I/O status table 1520. Additionally, because the most recent I/O status information is always available, there is no need to make a preliminary determination whether a particular piece of I/O status information should be acquired. Boolean control laws or other control laws are applied in a small number of steps based on the I/O status information already stored in the I/O status table 1520. Conditional control loops designed to avoid unnecessarily acquiring I/O status information are avoided and, therefore, processing time is reduced.

[0121] It may also be noted that, according to this arrangement, there is no need to synchronize the broadcasts of the interface modules 1420. Each interface module 1420 monitors the communication network 1661 to determine if the communication network 1661 is available and, if so, then the interface module broadcasts the I/O status information for local I/O devices 1441 and 1451. (Standard automotive communication protocols such as SAE J1708 or J1939 provide the ability for each member of the network to monitor the network and broadcast when the network is available.) Although it is desirable that the interface modules rebroadcast I/O status information at predetermined minimum intervals, the broadcasts may occur asynchronously.

[0122] The technique described in connection with Figs. 9-12 also provides an effective mechanism for detecting that an interface module 1420 has been rendered inoperable, for example, due to damage incurred in combat. As just noted, the interface modules 1420 rebroadcast I/O status information at predetermined minimum intervals. Each interface module 1420 also monitors the amount of time elapsed since an update was received from each remaining interface module 1420. Therefore, when a particular interface module 1420 is rendered inoperable due to combat damage, the

inoperability of the interface module 1420 can be detected by detecting the failure of the interface module 1420 to rebroadcast its I/O status information within a predetermined amount of time. Preferably, the elapsed time required for a particular interface module 1420 to be considered inoperable is several times the expected minimum rebroadcast time, so that each interface module 1420 is allowed a certain number of missed broadcasts before the interface module 1420 is considered inoperable. A particular interface module 1420 may be operable and may broadcast I/O status information, but the broadcast may not be received by the remaining interface modules 1420 due, for example, to noise on the communication network.

[0123] This arrangement also simplifies the operation of the data logger 1485 and automatically permits the data logger 1485 to store I/O status information for the entire control system 1412. The data logger 1485 monitors the communication network 1661 for I/O status broadcasts in the same way as the interface modules 1420. Therefore, the data logger 1485 automatically receives complete system updates and is able to store these updates for later use.

[0124] As previously noted, in the preferred embodiment, the interface modules 1423 and 1425 are used to transmit I/O status information between the various control systems 1511-1513. In an alternative arrangement, the interface module 1429 which is connected to all three of the communication networks 1661-1663 could be utilized instead. Although less preferred, the interface module 1429 may be utilized to receive I/O status information from each of the interface modules 1421-1428 and 1430, assemble the I/O status data into an updated I/O status table, and then rebroadcast the entire updated I/O status table 1520 to each of the remaining interface modules 1421-1428 and 1430 at periodic or aperiodic intervals. Therefore, in this embodiment, I/O status information for the all of the interface modules 1420 is routed through the interface module 1429 and the interface modules 1420 acquire I/O status information for non-local I/O devices 1440 and 1450 by way of the interface module 1429 rather than directly from the remaining interface modules 1420.

[0125] From the foregoing description, a number of advantages of the preferred military vehicle control system are apparent, some of which have already been mentioned. First, the control system is constructed and arranged such that failure at a single location does not render the entire vehicle inoperable. The control system has

the ability to dynamically reconfigure itself in the event that one or more interface modules are lost. By avoiding the use of a central control unit that is fixed at one location, and using a moving central control unit, there is no single point failure. If a master interface modules fails, another interface module will assume the position of the central control unit.

[0126] Additionally, because the interface modules are interchangeable, if one interface module is damaged, it is possible to field service the control system by swapping interface modules, obtained either from within the vehicle itself or from another vehicle, even if the other vehicle is not the same variant type. This allows the effectiveness of the military vehicle to be maximized by allowing undamaged interface modules to be utilized in the most optimal manner.

[0127] The use of the control system 1412 in connection with multipurpose modular vehicles is also advantageous. When the variant module is mounted to the chassis, all that is required is to connect power, ground and the communication network. Only one connector is required for all of the different types of variants. This avoids the need for a separate connector on the chassis for each different type of variant module, along with the additional unutilized hardware and wiring, as has conventionally been the approach utilized.

[0128] Moreover, since every interface module has a copy of the application program, it is possible to test each interface module as an individual unit. The ability to do subassembly testing facilitates assembly of the vehicle because defective mechanisms can be replaced before the entire vehicle is assembled.

[0129] Finally, the advantages regarding flexibility, robustness, ease of use, maintainability, and so on, that were discussed above in connection with fire fighting vehicles also apply to military vehicles. For example, it is often desirable in military applications to provide vehicles with consoles for both a left-hand driver and a right-hand driver. This option can be implemented without complex wiring arrangements with the preferred control system, due to the distributed data collection and the intelligent processing of information from input devices. Likewise, features such as "smart start" (in which vehicle starting is controlled automatically to reduce faulty starts due to operator error) can be implemented by the control system without any additional hardware.

D. **Network Assisted Monitoring, Service, and Repair**

[0130] Referring now to Fig. 13, a preferred embodiment of an equipment service vehicle 210 having a diagnostic system 212 according to an embodiment of the invention is illustrated. By way of overview, the diagnostic system 212 comprises an intelligent display module 214, a test interface module 221 connected to a plurality of sensors 222, and a plurality of additional vehicle control systems 224-230. The intelligent display module 214, the test interface module 221, and the plurality of additional vehicle control systems 224-230 are interconnected with each other by way of a communication network 232.

[0131] More specifically, the vehicle 210 is a military vehicle and, in particular, a medium tactical vehicle. However, it should be understood that the diagnostic system 212 of Fig. 13 could also be used with other types of military vehicles. For example, the diagnostic system 212 could be used in connection with heavy equipment transporter vehicles, which are used to transport battle tanks, fighting and recovery vehicles, self-propelled howitzers, construction equipment and other types of equipment. These types of vehicles are useable on primary, secondary, and unimproved roads and trails, and are able to transport in excess of 100,000 pounds or even in the range of 200,000 pounds or more. The diagnostic system 212 can also be used in connection with palletized load transport vehicles, in which a mobile truck and trailer form a self-contained system capable of loading and unloading a wide range of cargo without the need for forklifts or other material handling equipment. Such trucks are provided with a demountable cargo bed and a hydraulically powered arm with a hook that lifts the cargo bed on or off the truck. These trucks may be also provided with a crane to drop off the pallets individually if the entire load is not needed. Further, the diagnostic system 212 can also be used in connection with trucks designed for carrying payloads for cross country military missions. Such trucks may include, for example, cargo trucks, tractors, fuel servicing trucks, portable water trucks, and recovery vehicles (with crane and winch). Such trucks are capable of passing through water crossings three or four or more feet deep. These trucks can also be used for missile transports/launchers, resupply of fueled artillery ammunition and forward area rearm vehicles, refueling of tracked and wheeled vehicles and helicopters, and recovery of disabled wheeled and tracked vehicles. The diagnostic system 212 can be used in connection with a wide range of other military vehicles as well.

[0132] The intelligent display module 214 provides an operator interface to the diagnostic system 212 and also provides intelligence used to conduct diagnostic tests and other services. In particular, the intelligent display module 214 includes a test control module 215 (which further includes a microprocessor 216 and a diagnostic program 217) and an operator interface 218 (which further includes a display 219 and a keypad 220) (see Fig. 14).

[0133] In the preferred embodiment, the test control module 215 and the operator interface 218 are provided as a single, integrated unit (namely, the intelligent display module 214) and share the same housing as well as at least some of the internal electronics. Other arrangements are possible, however. For example, as can be easily imagined, it would also be possible to provide the test control module 215 and the operator interface 218 in the form of separate physical units, although this arrangement is not preferred for reasons of increased cost and parts count. Both the test control module 215 and the operator interface 218 can be obtained in the form of a single, integrated unit from Advanced Technology, Inc., Elkhart, IN 46517. This product provides a generic flat panel 4 line × 20 character display 219, four button keypad 220, microprocessor 216, and memory that is capable of being programmed with a program (such as the diagnostic program 217) to customize the intelligent display module for a particular application. Of course, a more (or less) elaborate intelligent display module could also be utilized. For example, if on-line parts ordering capability is incorporated as detailed below, then a display module with an SVGA flat touch screen monitor with a microprocessor and memory may be preferred. Also, the test control module 215 may be implemented using one of the interface modules 20, 30, 1420 previously described, providing that the interface module has sufficient graphics capability to drive a display.

[0134] Also in the preferred embodiment, the intelligent display module 214 is semi-permanently mounted within the vehicle 210. By semi-permanently mounted, it is meant that the intelligent display module 214 is mounted within the vehicle 210 in a manner that is sufficiently rugged to withstand normal operation of the vehicle for extended periods of time (at least days or weeks) and still remain operational. However, that is not to say that the intelligent display module 214 is mounted such that it can never be removed (e.g., for servicing of the intelligent display module) without significantly degrading the structural integrity of the mounting structure

employed to mount the intelligent display module 214 to the remainder of the vehicle 210. The intelligent display module 214 is preferably mounted in an operator compartment of the vehicle 210, for example, in a storage compartment within the operator compartment or on an operator panel provided on the dashboard.

[0135] The operation of the test control module 215, and in particular of the microprocessor 216 to execute the diagnostic program 217, is shown and described in greater detail below in conjunction with the flowchart of Fig. 16. In general, the microprocessor 216 executes the diagnostic program 217 to diagnose subsystem faults, to display fault information, to maintain vehicle maintenance records, and to perform data logging for system diagnosis and/or for accident reconstruction. Depending on the application, it may be desirable to incorporate additional services as well, or to incorporate fewer than all of these services.

[0136] The operator interface 218 includes the display 219 which is used to communicate (and, in particular, to display) information to the operator. For example, the display 219 is used to prompt the operator to enter information into the keypad 220, or to take certain actions with respect to the vehicle during testing (e.g., bring the engine to a specified RPM level). The display 219 is also used to display a menu or series of menus to allow the operator to select a test to be performed or to select another service of the intelligent display module 214 to be utilized. The display 219 is also used to display status information during system startup and during testing, and to display any error messages that arise during system startup or during testing. The display 219 is also used to display input data and fault mode indicators from control systems 224-230, and any other information from additional vehicle subsystems. The display 219 is also used to display information from discrete sensors such as the sensors 222. The display 219 is also used to display the results of diagnostic tests that are performed (e.g., a pass/fail message or other message).

[0137] Preferably, the display 219 displays all of this information to the operator in a user-friendly format as opposed to in the form of codes that must be interpreted by reference to a separate test or service manual. This is achieved in straightforward fashion by storing in the memory of the intelligent display module 214 information of the type commonly published in such manuals to facilitate manual interpretation of such codes, and using this information to perform the translation automatically. Likewise, as previously noted, the display 219 is used to prompt the operator to take

certain actions with respect to the vehicle during testing and to otherwise step the operator through any test procedures, without reference to a test manual. This allows the amount of operator training to be reduced.

[0138] The operator interface 218 also includes the keypad 220 which is used to accept or receive operator inputs. For example, the keypad 220 is used to allow the user to scroll through and otherwise navigate menus displayed by the display 219 (e.g., menus of possible tests to be performed on the vehicle 210), and to select menu items from those menus.

[0139] As previously noted, it would also be possible to utilize a more elaborate intelligent display module. For example, a more elaborate keypad 220 could be utilized if more data entry capability is desired. In this regard, however, it is noted that the intelligent display module 214 also preferably includes a communication port that allows the display module to communicate with a personal computer 233 by way of a communication network 232 (see Fig. 14). The personal computer 233 can be used to retrieve, manipulate and examine data stored within the intelligent display module 214. For example, if the intelligent display module 214 includes a data logger as described below, the personal computer can be used to retrieve and examine the information stored by the data logger. Likewise, if the intelligent display module 214 implements a vehicle maintenance jacket, the personal computer 233 can be used to retrieve and modify data stored in the vehicle maintenance jacket. Further, using the personal computer 233, it is possible to integrate the diagnostic system 212 with an interactive electronic technical manual (IETM), to allow the interactive electronic technical manual to access the data available from the diagnostic system 212.

[0140] The test interface module 221 accepts requests from the intelligent display module 214 for information from the sensors 222, retrieves the requested information from the respective sensor 222, converts input signals from the respective sensor 222 into a format that is compatible with the communication network 232, and transmits the information from the respective sensor 222 to the intelligent display module 214 via the communication network 232. The test interface module 221 is therefore implemented as a passive unit with no standard broadcasts that burden the communication network 232. As a result, in operation, the test interface module 221 does not regularly transmit data on the communication network 232. Rather, the test interface module 221 passively monitors the communication network 232 for

information requests directed to the interface module 221. When an information request is received, the test interface module 221 obtains the requested information from the relevant sensor 222, and then transmits the requested information on the communication network 232 to the intelligent display module 214. Alternatively, in accordance with the arrangement described in Figs. 8-11, it may be desirable to implement the test interface module 221 as an active unit that broadcasts input status information in the same manner as the interface modules 1420.

[0141] The test interface module 221 may, for example, include as many inputs as there are sensors 222. Each input may include associated switches for configuring the input, an analog-to-digital converter to convert analog signals to a digital format, and any other signal processing circuitry. The number of inputs is not important, since it is possible to use fewer test interface modules each with a larger number of inputs, or more test interface modules each with a smaller number of inputs. The number of inputs is not limited in any particular way and is determined by need.

[0142] In practice, the test interface module 221 may be a commercially available unit capable of putting information from discrete sensors onto a communication network such as SAE (Society of Automotive Engineers) J1708. The test interface module 221 preferably also meets applicable standards for underhood installation, such as SAE J1455, to allow the test interface module to be located in close proximity to the sensors 222 to reduce wiring. The test interface module may, for example, be obtained from Advanced Technology Inc., Elkhart, Indiana 46517 (PN 3246282). Again, however, a wide range of devices of varying construction and complexity could be utilized to implement the test interface module 221.

[0143] The test interface module 221 is connected to the plurality of sensors 222 which are each capable of obtaining information pertaining to the health and operation of a vehicle subsystem. "Health" and "operation" are interrelated and information that pertains to one will, at least to some extent, pertain to the other as well. The sensors 222 are discrete sensors in the sense that they are not integrally provided with the control systems 224-230 and associated controlled mechanical systems (e.g., engine, transmission, and so on) 234-240. The sensors are add-on devices that are used only in connection with the intelligent display module 214. In general, discrete sensors are preferably only used when the information provided by the sensor is not otherwise available on the communication network 232. In Fig. 14, the sensors 222 are shown

to include a fuel filter inlet pressure sensor 222a, fuel pump outlet pressure sensor 222b, fuel return pressure sensor 222c, oil filter sensors 222d, an air cleaner pressure sensor 222e, a fuel differential pressure switch 222f, and a shunt resistor 222g (used to determine compression imbalance based on unequal current peaks in the starter current).

[0144] In addition to the intelligent display module 214 and the test interface module 221, the diagnostic system 212 also includes a plurality of additional vehicle control systems 224-230, as previously noted. As shown in Fig. 14, the control system 240 is a central tire inflation control system that controls a central tire inflation system (CTIS) 34, the control system 226 is an anti-lock brake control system that controls an anti-lock brake system (ABS) 236, the control system 228 is a transmission control system that controls a transmission 238, and the control system 230 is an engine control system that controls an engine 240. The vehicle subsystems formed by the mechanical systems 234-240 and associated control systems 224-230 are conventional and are chosen in accordance with the intended use of the vehicle 210.

[0145] The control systems 224-230 each store information pertaining to the health and operation of a respective controlled system. The control systems 224-230 are capable of being queried and, in response, making the requested information available on the communication network 232. Because the vast amount of information required for performing most diagnostic tests of interest is available from the control systems 224-230 by way of the communication network 232, it is possible to drastically reduce the number of discrete sensors 222 that are required. Thus, as just noted, discrete sensors are preferably only used when the information provided by the sensor is not otherwise available on the communication network 232.

[0146] Typically, each of the control systems 224-230 comprises a microprocessor-based electronic control unit (ECU) that is connected to the communication network 232. When the intelligent display module 214 requires status information pertaining to one of the mechanical systems 234-240, the intelligent display module 214 issues a request for the information to the respective one of the control systems 224-230. The respective control system then responds by making the requested information available on the communication network 232.

[0147] Typical ECUs for transmission and engine control systems are capable of producing fault codes and transmitting the fault codes on the communication network 232. Depending on the type of fault, the fault codes may be transmitted automatically or alternative only in response to a specific request for fault information. Typical ECUs for central tire inflation systems and anti-lock brake systems also transmit fault codes but, in most commercially available systems, fault codes are transmitted only in response to specific requests for fault information. When a fault code is transmitted on the communication network 232, the intelligent display module 214 receives the fault codes from the communication network 232, interprets the fault codes, and displays the interpreted fault codes to a human operator using the display 219.

[0148] It may be noted that the diagnostic system 212 may be implemented as a stand-alone system or in the context of the control systems 12 and 1412 described in connection with Figs. 1-12. For example, in the context of the control system 1412, the communication network 232 and the communication network 1460 may be the same network, such that the intelligent display module 214 and the test interface module 221 are disposed on the communication network 1460 along with the interface modules 1420. When combined in this manner, the anti-lock brake control system 226 and anti-lock brake control system 1495 are in practice the same devices, as are the transmission control system 228 and the transmission control system 1493, and the engine control system 230 and the engine control system 1491, and also as are the respective controlled subsystems. The intelligent display module 214 maintains a dynamically updated I/O status table 1520 by listening to the I/O status broadcasts made by the interface modules 1420 and the control systems 224-230, as described in connection with Figs. 8-11. This makes it possible to connect the sensors 222 to the communication network 232 by way of one or more of the interface modules 1420 rather than through the use of a separate dedicated test interface module, and making it possible to eliminate redundant sensors. A further advantage of this arrangement is that the intelligent display module 214 has access to all of the I/O status information provided by the interface modules 1420.

[0149] Referring now to Fig. 15, in general, during operation, the display 219 displays menus to the operator and the keypad receives operator inputs used to navigate the menu, make menu selections, and begin testing. Assuming other

services are also provided, the operator is first prompted to select an option from among a list of options that includes options of other services provided by the intelligent display module 214. The list of options may include, for example, an option 250 to perform vehicle diagnostic testing, an option 252 to view engine codes, an option 254 to view transmission codes, an option 256 to view ABS codes, an option 258 to view CTIS codes, an option 260 to view and/or modify data in the vehicle maintenance jacket, and an option 262 to view information stored in a data logger. Given that the display 219 is a four line display in the preferred embodiment, a vertically sliding winding 264 is used to scroll through the options, and the user presses a select button on the keypad 220 when a cursor 266 is positioned on the desired option. As previously noted, other options may also be provided.

[0150] Referring now to Fig. 16, a flowchart showing the operation of the diagnostic system of Figs. 13-14 to perform a diagnostic test is illustrated. In connection with military vehicles, the diagnostic system 212 may for example be made capable of performing the following diagnostic tests, all of which provide information pertaining to the health and operation of the tested subsystem:

Test	Test Description and Application	Exemplary Measurement Range(s)
	ENGINE TESTS	
Engine RPM (AVE)	Measures average speed of engine crankshaft.	50 — 5000RPM
Engine RPM, Cranking SI only	Measures cranking RPM. Performed with ignition ON. Inhibit spark plug firing allowing cranking without starting.	50 — 1500RPM
Power Test (RPM/SEC)	Measures engine's power producing potential in units of RPM/SEC. Used when programmed engine constants and corresponding Vehicle Identification Number (VID) have not been established.	500 — 3500RPM/s
Power Test (% Power)	Measures percentage of engine's power producing potential compared to full power of a new engine.	0 — 100%

Test	Test Description and Application	Exemplary Measurement Range(s)
Compression Unbalance (%)	Evaluates relative cylinder compression and displays percent difference between the highest and the lowest compression values in an engine cycle.	0 – 90%
	IGNITION TESTS	
Dwell Angle (TDC)	Measures number of degrees that the points are closed.	10 – 72 @ 2000RPM
Points Voltage (VDC)	Measures voltage drop across the points (points positive to battery return).	0 – 2VDC
Coil Primary	Measures voltage available at the coil positive terminal of the operating condition of the coil.	0 – 32VDC
	FUEL/AIR SYSTEM TESTS	
Fuel Supply Pressure (psi)		0 – 100psi
Fuel Supply Pressure (psi)	This test measures the outlet pressure of the fuel pump.	0 – 10psi 0 – 30psi 0 – 100psi 0 – 300psi
Fuel Return Pressure (psi)	Measures return pressure to detect return line blockage, leaks, or insufficient restrictor back pressure.	0 – 100psi
Fuel Filter Pressure Drop (PASS/FAIL)	Detects clogging via opening of a differential pressure switch across the secondary fuel filter.	PASS/FAIL
Fuel Solenoid Voltage (VDC)	Measures the voltage present at the fuel shutoff solenoid positive terminal.	0 – 32VDC
Air Cleaner Pressure Drop (RIGHT) (In H_2O)	Measures suction vacuum in air intake after the air cleaner relative to ambient air pressure to detect extent of air cleaner clogging.	0 – 60 in. H_2O
Air Cleaner Pressure Drop (LEFT) (In H_2O)	Second air cleaner on dual intake systems.	0 – 60 in. H_2O
Turbocharger Outlet Pressure (RIGHT) (In Hg)	Measures discharge pressure of the turbocharger.	0 – 50 in. Hg
Turbocharger Outlet	Second turbocharger on dual	0 – 50 in. Hg

Test	Test Description and Application	Exemplary Measurement Range(s)
Pressure (LEFT) (In Hg)	intake systems.	
Airbox Pressure (In Hg)	Measures the airbox pressure of two stroke engines. This measurement is useful in detecting air induction path obstructions or leaks.	0 – 20 in. Hg 0 – 50 in. Hg
Intake Manifold Vacuum (In Hg)	Spark ignition engine intake system evaluation.	0 – 30 in. Hg
Intake Manifold Vacuum Variation (In Hg)	Spark ignition engine intake system evaluation.	0 – 30 in. Hg
	LUBRICATION/COOLING SYSTEM TESTS	
Engine Oil Pressure (psi)	Measures engine oil pressure.	0 – 100psi
Engine Oil Filter	Measures the pressure drop across the engine oil filter as indicator of filter element clogging.	0 – 25psi
Engine Oil Temperature (°F)	Primarily applicable to air cooled engines. Requires transducer output shorting switch on vehicle to perform system zero offset test.	120 – 300°F
Engine Coolant Temperature (°F)	Transducer output shorting switch on vehicle required.	120 – 300°F
	STARTING/CHARGING SYSTEM TESTS	
Battery Voltage (VDC)	Measure battery voltage at or near battery terminals.	0 – 32 VDC
Starter Motor Voltage (VDC)	Measures the voltage present at the starter motor positive terminal.	0 – 32 VDC
Starter Negative Cable Voltage Drop (VDC)	Measures voltage drop on starter path. A high voltage indicates excessive ground path resistance.	0 – 2 VDC
Starter Solenoid Volts (VDC)	Measures voltage present at the starter solenoid's positive terminal. Measures current through battery ground path shunt.	0 – 32 VDC

Test	Test Description and Application	Exemplary Measurement Range(s)
Starter Current, Average (amps)	Measures starter current.	0 — 1000A 0 — 2000A
Starter Current First Peak (Peak Amps, DC)	Provides a good overall assessment of complete starting system. Tests condition of the starting circuit and battery's ability to deliver starting current. The measurement is made at the moment the starter is engaged and prior to armature movement. Peak currents less than nominal indicate relatively high resistance caused by poor connections, faulty wiring, or low battery voltage.	0 — 1000A 0 — 2000A
Battery Internal Resistance (Milliohms)	Evaluate battery condition by measuring battery voltage and current simultaneously.	0 — 999.9mohm
Starter Circuit Resistance (Milliohms)	Measures the combined resistance of the starter circuit internal to the batteries.	0 — 999.9mohm
Battery Resistance Change (Milliohms/sec)	Measures rate of change of battery resistance as an indicator of battery condition.	0 — 999.9mohm/s
Battery Current	Measures current to or from the battery.	-999 — 1000A -999 — 2000A
Battery Electrolyte Level (PASS/FAIL)	Determines whether electrolyte in the sensed cell is of sufficient level (i.e., in contact with electrolyte probe).	PASS/FAIL
Alternator/Generator Output Voltage (VDC)	Measures output voltage of generator/alternator.	0 — 32 VDC
Alternator/Generator Field Voltage (VDC)	Measures voltage present at alternator/generator field windings.	0 — 32 VDC
Alternator/Generator Negative Cable Voltage Drop (VDC)	Measures voltage drop in ground cable and connection between alternator/generator ground terminal and battery negative terminal.	0 — 2 VDC
Alternator Output Current Sense (VAC-RMS)	Measures voltage output at the current transformer in 650 ampere alternator.	0 — 3 VAC
Alternator AC Voltage Sense	Measures alternator output voltage.	0 — 22 VAC

Test	Test Description and Application	Exemplary Measurement Range(s)
(VAC-RMS)		

[0151] In general, the specific diagnostic tests that are performed will be selected depending on the application, including the type of equipment utilized by the vehicle 210. Most or all tests may be simple in nature from a data acquisition standpoint, involving primarily bringing the vehicle to a particular operating condition (e.g., engine speed), if necessary, and obtaining information from a suitable transducer constructed and placed to measure the parameter of interest, although more elaborate tests could also be utilized. Any number of different vehicle parameters can be measured, each providing a separate data point regarding the operational health of the vehicle. By providing an operator with enough data points regarding the operational health of the vehicle, the operator can use this information in a known way to determine whether the vehicle is in good working order, or whether some subsystem or component thereof needs to be repaired or replaced.

[0152] At step 302, once the vehicle diagnostic option is selected, the display 219 displays a menu of various tests that are available to the operator, and the operator is prompted to select a test from the test menu. Again, the list of options may comprise dozens of options, such as some or all of those listed above, and/or tests other than those listed above, and the operator can scroll through the menu and selected the desired option.

[0153] At Step 304, the operator is prompted to perform a vehicle related action. This step, which may or may not be necessary depending on the type of test performed, may be used to prompt the operator to start the engine to develop fuel pressure, oil pressure, and so on, depending on which vehicle parameter is tested. For example, if it is desired to test the operational health of the battery, then the operator may be prompted to engage the starter for a predetermined amount of time to establish a current draw on the battery.

[0154] At Step 306, the intelligent display module 214 issues a request for information from the test interface module 221 and/or from one or more of the control systems 224-230. As previously noted, the test interface module 221 does not

continually broadcast information on the communication network 232, because the sensors 222 connected to the test interface module are used only for diagnostic testing and because presumably diagnostic testing will be performed only infrequently. Therefore, when the intelligent display module 214 needs information from one of the sensors 222 pursuant to a test requested to be performed by the operator at the operator interface 218, the intelligent display module 214 requests the test interface module 221 for this information.

[0155] Alternatively, the needed information may be of a type that is available from one of the control systems 224-230. The control systems 224-230 are not only able to acquire information from sensors located within the systems 234-240, but are also able to maintain information derived from sensors located within the systems 234-240. For example, the engine control system 230 may maintain information pertaining to the average RPM of the engine, which is a parameter that is not directly measurable but that can be easily calculated based on parameters that are directly measurable. Through the communication network 232, all of this information is made available to the diagnostic system 212. When the intelligent display module 214 needs information from one of the control systems 224-230 pursuant to a test requested to be performed by the operator at the operator interface 218, the intelligent display module 214 requests the respective control system for this information.

[0156] At Step 308, the requested information is retrieved from one of the sensors 222 by the test interface module 221, or from memory or an internal sensor by the respective control system 224-230. At step 309, the information is transmitted from the test interface module 221 or from one of the control systems 224-230 to the intelligent display module 214 by way of the communication network 232.

[0157] Alternatively, the needed information may be of a type that is available from one of the interface modules 1420. In this case, the information is readily available in the I/O status table 1520 maintained by the intelligent display module 214, without there being a need to specifically request the information.

[0158] At step 312, the input status information is processed at the intelligent display module 214. For example, if fuel supply pressure is measured by one of the sensors 222, then the measured fuel supply pressure may be compared with upper

and lower benchmark values to determine whether the fuel pressure is at an acceptable level, or whether it is too high or too low. Finally, at step 314, the results of the test are displayed to the operator.

[0159] As has been previously noted, in addition to performing diagnostic tests, the intelligent display module 214 can also be used to provide other services to an operator. For example, the intelligent display module 214 can be used to allow the operator to view engine codes, to view transmission codes, to view ABS codes, and to view CTIS codes. In practice, these services can be implemented simply by allowing acquiring the respective codes from the respective control system 224-230, and displaying the codes to the operator. Additionally, the control systems 224-230 may automatically transmit fault information on the communication network 232, and the intelligent display module 214 can listen for such fault information and display the fault information to the user when it appears on the communication network 232.

[0160] The intelligent display module 214 also includes sufficient memory to allow maintenance information to be stored therein to implement maintenance jacket functionality. The maintenance log may consist of a table comprising a variety of fields, such as registration numbers, chassis serial number, vehicle codes, and dates and descriptions of maintenance actions performed. This information may be retrieved and manipulated utilizing the computer 234 when the vehicle 210 is taken to a maintenance depot. If the computer 234 is provided with an interactive electronic technical manual (IETM) for the vehicle 210, this allows the IETM to have access to all of the diagnostic data acquired by the intelligent display module 214 as well as all of the maintenance data stored by the intelligent display module 214. This greatly enhances the ability to perform vehicle maintenance and diagnostics on the vehicle 210.

[0161] Additionally, sufficient memory capacity is preferably provided so that status information from the test interface module 221 as well as the control systems 224-230 can be sampled and stored at frequent, regular intervals in a circular data queue (i.e., with new data eventually replacing old data in the circular queue). This allows the intelligent display module 214 to provide a data logger service so that input data acquired over a period of time can be viewed to allow an assessment of dynamic conditions leading to a fault to be evaluated. Additionally, the vehicle is preferably provided with one more sensors that indicate whether a severe malfunction (e.g., the

vehicle being involved in an accident) has occurred. When inputs from these sensors indicates that a severe malfunction has occurred, data logging is stopped, so that data leading up to the severe malfunction is stored in a manner similar to a so-called "black box recorder."

[0162] Referring now to Figs. 17-20, as previously mentioned, the control systems 12 and 1412 can be used in connection with a variety of different types of equipment service vehicles.. The same is true of the diagnostic system 212. Figs. 17-20 show some of the vehicles that can employ the control systems 12 and 1412 and/or the diagnostic system 212.

[0163] Referring first to Fig. 17, Fig. 17 is a schematic view of a fire fighting vehicle 310 that utilizes the diagnostic system 212. The fire fighting vehicle 310 comprises a water dispensing system 315 including water hoses, pumps, control valves, and so on, used to direct water at the scene of a fire. The fire fighting vehicle 310 may also comprise a foam dispensing system 318 as an alternative fire extinguishing system. The fire fighting vehicle 310 also comprises emergency lighting 324, which may in practice be red and white or red, white and blue flashing lights, as well as an emergency horn 326 and an emergency siren 328 used, among other things, for alerting motorists to the presence of the fire fighting vehicle 310 in transit to or at the scene of a fire. The fire fighting vehicle 310 may also comprise an extendable aerial 331 that supports a basket 332 used to vertically carry fire fighting personnel to an emergency situation at the scene of a fire. The diagnostic system 212 may be used to diagnose vehicle malfunctions in the manner described above in connection with the vehicle 210, as well as to diagnose malfunctions of the specialized systems described above found on fire fighting vehicles. Of course, the features of the fire fighting vehicle 310 in Fig. 17 and the fire fighting vehicle 10 of Figs. 1-2 (including the features pertaining to the I/O status table 1520 described in connection with Figs. 9-12) may be combined.

[0164] Referring now to Fig. 18, a schematic view of another type of equipment service vehicle 360 that utilizes the diagnostic system 212 is shown. The equipment service vehicle 360 is a mixing vehicle such as a cement mixing vehicle. The mixing vehicle 360 comprises a rotatable mixing drum 362 that is driven by engine power from the engine 240 via a power takeoff mechanism 364. The mixing vehicle 360 also includes a dispenser or chute 368 that dispenses the mixed matter or material,

for example, mixed cement. The chute 368 is moveable to allow the mixed cement to be placed at different locations. The chute 368 may swing from one side of the concrete mixing vehicle 360 to the other side. Rotation of the mixing drum 362 is controlled under operator control using an operator control panel 366 including chute and drum controls comprising one or more joysticks or input devices. Additional controls may be provided inside the operator compartment for driver or passenger control of the drum 362 and chute 368, for example, a dash-mounted control lever to control drum rotation direction, a console-mounted joystick to control external hydraulic valves for chute up/down and swing right/left. Drum rotation start/stop may be controlled using a switch on top of the joystick lever. Outside controls mounted may include chute up/down and swing right/left and remote engine throttle. Drum rotation direction controls may be mounted on right side of front fender. The diagnostic system 212 is used to diagnose vehicle malfunctions in the manner described above in connection with the vehicle 210, as well as to diagnose malfunctions of the specialized systems described above found on mixing vehicles.

[0165] The mixing vehicle 360 may also include the control system 1412 described above. In such an arrangement, for example, an interface module 1420 is located near the operator control panel 366 receiving operator inputs which the control system 1412 uses to control of the mixing drum 362. An additional interface module 1420 may also be provided in an operator compartment of the mixing vehicle 360 to interface with input devices inside the operator compartment which permit driver control of the mixing drum 362. Interface modules 1420 are also connected to output devices such as a drive mechanism that controls rotation of the mixing drum 362 and a drive mechanism that controls movement of the chute 368. For example, if drum and chute movement are driven by engine power from the engine 240 via a power takeoff mechanism 364, the interface modules 1420 may be used to control output devices 1450 in the form of electronically controlled hydraulic valves that control the flow of hydraulic power from the engine to the mixing drum and electronically controlled hydraulic valves that control the flow of hydraulic power from the engine to the chute. Alternatively, if electric drive motors are used to drive drum and chute movement (for example, in the context of a mixing vehicle implemented using the electric vehicle 1910 as described above), then the interface modules 1420 may be used to control the drive motors. In operation, inputs are received from the operator controls at one interface module 1420 may be transmitted to the interface modules

1420 that control the valves during I/O status broadcasts, which in turn control operation of the drum 362 and chute 368 based on the operator inputs. Other devices, such as air dryers, air compressors, and a large capacity (e.g., 150 gallon) water system may be connected to interface modules 1420 and controlled in accordance with operator inputs received from similar input devices at the operator panels and transmitted over the communication network. Additional interface modules 1420 may be used to receive inputs from input devices 1440 in the operator compartment and control output devices 1450 such as FMVSS lighting as described above.

[0166] Referring now to Fig. 19, a schematic view of another type of equipment service vehicle 370 that utilizes the diagnostic system 212 is shown. The equipment service vehicle 370 is a refuse handling vehicle and comprises one or more refuse compartments 372 for storing collected refuse and other materials such as goods for recycling. The refuse handling vehicle 370 also includes a hydraulic compactor 374 for compacting collected refuse. The hydraulic compactor 374 is driven by engine power from the engine 240 via a power takeoff mechanism 376. The refuse handling vehicle may also include an automatic loading or tipping system 378 for loading large refuse containers and for transferring the contents of the refuse containers into one of the compartments 372. The loading system 378 as well as the hydraulic compactor may controlled under operator control using a control panel 379. The diagnostic system 212 may be used to diagnose vehicle malfunctions in the manner described above in connection with the vehicle 210, as well as to diagnose malfunctions of the specialized systems described above found on refuse handling vehicles.

[0167] The refuse handling vehicle 370 may also include the control system 1412 described above. In such an arrangement, an interface module 1420 is located near the hydraulic compactor 374 and controls valves associated with the hydraulic compactor 374. Another interface module 1420 located adjacent the automatic loading or tipping system 378 controls hydraulic valves associated with the system 378. Again, the interface modules 1420 may be used to control the drive motors instead of hydraulic valves in the context of . Another interface module 1420 is located adjacent the operator control panel 379 and is connected to receive operator inputs from input devices 1440 which are part of the control panel 379. In operation, inputs are received from the operator controls at one interface module 1420 and are

transmitted to the interface modules 1420 that control the hydraulic valves during I/O status broadcasts, which in turn control operation of the hydraulic compactor 374 and loading system 378 based on the operator inputs. Additional interface modules may be used to receive inputs from input devices 1440 in the operator compartment and control output devices 1450 such as FMVSS lighting as described above.

[0168] Referring now to Fig. 20, a schematic view of another type of equipment service vehicle 380 that utilizes the diagnostic system 212 is shown. The equipment service vehicle 380 is a snow removal vehicle and comprises a snow removal device 382 which may, for example, be a rotary blower, plow, or sweeper. The snow removal device 382 may be driven by engine power from the engine 240 via a power takeoff mechanism 384 to remove snow from a region near the snow removal vehicle 380 as the snow removal vehicle 380 is moving. The diagnostic system 212 may be used to diagnose vehicle malfunctions in the manner described above in connection with the vehicle 210, as well as to diagnose malfunctions of the specialized systems described above found on snow removal vehicles.

[0169] The snow removal vehicle 380 may also include the control system 1412 described above. An interface module 1420 located adjacent an operator compartment receives operator inputs from input devices 1440 located in the operator compartment. One or more additional interface modules 1420 receive the operator input during I/O status broadcasts, and in response controls various output devices 1450 such as FMVSS lighting as described above. Preferably, the snow removal vehicle 380 employs the teachings of U.S. Pat. No. 6,266,598, entitled "Control System and Method for a Snow Removal Vehicle," hereby expressly incorporated by reference. The preferred snow removal vehicle disclosed therein comprises an impeller, an engine system, and an engine control system. The engine system includes a traction engine which is coupled to drive wheels of the snow removal vehicle, and is adapted to drive the drive wheels to drive movement of the snow removal vehicle. The engine system also includes an impeller engine which is coupled to the impeller and is adapted to drive the impeller to drive snow removal. The engine control system receives feedback information pertaining to operation of the impeller, and controls the engine system based on the feedback information. The engine control system includes a communication network, a microprocessor-based traction engine control unit which is coupled to the traction engine and is adapted to control

the traction engine, a microprocessor-based impeller engine control unit which is coupled to the impeller engine and is adapted to control the impeller engine, and a microprocessor-based system control unit. The system control unit is coupled to the traction engine control unit and the impeller engine control unit by way of the network communication link. The system control unit is adapted to receive the feedback information pertaining to the operation of the impeller, and to generate a control signal for the traction engine control unit based on the feedback information.

[0170] Advantageously, due to the utilization of a network architecture in the preferred embodiment, the diagnostic system is able to use sensors and other sources of information that are already provided on the vehicle, because it is able to interact with other vehicle control systems such as the engine control system, the anti-lock brake control system, the central tire inflation control system, and so on, via a communication network. The fact that the diagnostic system is connected to these other systems, which are all typically capable of providing a vast array of status information, puts this status information at the disposal of the diagnostic system.

[0171] Further, due to the utilization of an intelligent display module in the preferred embodiment, it is possible for the intelligent display module to be connected to the communication network and collect information as necessary for a variety of purposes. Thus, the preferred intelligent display module is microprocessor-based and is capable of executing firmware to provide additional functionality such as data logging, accident reconstruction, and a vehicle maintenance record. Again, this functionality can be achieved by taking advantage of the information available from the vehicle subsystems by way of the network architecture.

[0172] Moreover, by mounting the intelligent display module on board the vehicle in the preferred embodiment, for example, in an operator compartment, it is not necessary to bring the vehicle to a maintenance depot to have vehicle malfunctions diagnosed. The services offered by the intelligent display module are available wherever and whenever the vehicle is in operation.

[0173] Referring now to Fig. 21, an overview of a system 410 that utilizes the diagnostic system 212 is illustrated. The system 410 interconnects the computing resources of a plurality of vehicles 411-414 with those of a maintenance center 416, a manufacturer facility 417, and a fleet manager 418 using a communication network

420. Of course, although four vehicles are shown, it is possible to use the system 410 in connection with fewer or additional vehicles. Also, although in the preferred embodiment the system 410 includes all of the devices shown in Fig. 21, it is also possible to construct a system that uses only some of the devices in Fig. 21.

[0174] The vehicles 411-414 are assumed to be military vehicles, although the vehicles could also be any of a variety of other types of vehicles including the other types of equipment service vehicles described herein (e.g., fire fighting vehicles, concrete transport and delivery vehicles, military vehicles, ambulances, refuse transport vehicles, liquid transport vehicles, snow removal vehicles, and so on). The vehicles 411 each have a control system 1412 as previously described, and therefore the on-board computer system 422 includes a plurality of interface modules 1420. The vehicles 411-414 each include an on-board computer system 422 which further includes the test control module 215 and the operator interface 218 previously described above in connection with Figs. 13-20. The on-board computer system 422 also includes a web server program 423 and is coupled to a global positioning system (GPS) receiver 425. Although these features are discussed in connection with the vehicle 411 in Fig. 21, it should be noted that the vehicles 412-414 include these features as well (although the vehicles 411-414 need not all be the same type of vehicle).

[0175] The web server program 423, which is executed on the intelligent display module 214 or on another computer connected to the network 232, allows an operator using the maintenance center computer system 424, the manufacturer computer system 432 and/or the fleet management computer system 437 to access vehicle information. For example, the operator is given access to the information in the I/O status table 1520 maintained by the intelligent display module 214 using a web interface. Thus, the operator can click on depictions of individual input devices 40, 1440 and output devices 50, 1550, and the web server 423 responds by providing information as to the status of those devices. Additionally, the operator is also given access to information from the control systems 224-230. Thus, the operator can click on a depiction of the central tire inflation system 234 to obtain central tire inflation system information, can click on a depiction of the brake system 236 to obtain brake system information, can click on a depiction of the transmission system 238 to obtain transmission system information, and/or can click on a depiction

of the engine 240 to obtain engine information. When the web server 423 receives these operator inputs, the web server 423 provides the requested information to the operator by way of the communication network 420. It may also be desirable to provide the on-board computer system 422 with web-browser functionality to allow the on-board computer system 422 to obtain information from the maintenance center computer system 424 and/or the manufacturer computer system 432.

[0176] Rather than clicking on various vehicle components, a list of I/O states for all or some of the I/O devices 1440 and 1450 and/or I/O status information from the control systems 224-230 may be displayed to the operator. For example, a particular input or output may be identified with a descriptive identifier (e.g., "PTO Solenoid") with an indication as to whether the input/output is on or off (e.g., by placing the words "on" or "off" next to the descriptive identifier, or through the use of a color indicator whose color varies according to I/O state). For analog I/O devices, meters, gauges, or other image corresponding to the I/O device may be displayed, without displaying the entire vehicle and without use of the web server 423 and web browsers 430, 435, 438. Various examples are shown in Figs. 28-38. All of the I/O status information is preferably capable of being transferred automatically and on a real-time basis for real-time remote monitoring of any aspect of operation of the vehicle 411.

[0177] In an alternative embodiment, the web server 423 may be provided in an off-board computer system and the on-board computer system 422 can post information to the web server 423. The off-board computer system used to implement the web server may for example be any of the computer systems 424, 432, 437 discussed below. This would allow the same functionality to be achieved while at the same time reducing the amount of communication required between the on-board computer system 422 and the off-board computer systems that wish to view information from the on-board computer system 422.

[0178] The GPS receiver 425 permits vehicle position to be determined. The on-board computer system 422 can then transmit the vehicle position information to the computer systems 424, 432, 437 along with the other I/O status information.

[0179] The maintenance center 416 is a facility to which the vehicles 411-414 may be taken for maintenance. For example, in the context of a fleet of military vehicles, the maintenance center 416 may be a maintenance depot that is used to service the

military vehicles. For a fleet of municipal vehicles, the maintenance center may be a municipal facility where the vehicles are stored and maintained. Alternatively, the maintenance center 416 may be operated by a private outside contractor such as a service station hired to maintain and service municipal vehicles. Likewise, where the fleet of vehicles is privately owned, the maintenance center 416 may be internally operated or operated by an outside contractor. The structure and functions of the maintenance center computer system 424 may be combined with those of the computer systems 432 or 437, for example, where the maintenance center is owned/operated by the manufacturer 417 or the fleet manager 418.

[0180] The computer system 416 of the maintenance center 416 further includes a maintenance scheduling system 427, an inventory management system 428, a diagnostic program 429 and a browser and/or server program 430. The maintenance scheduling system 427 is a program executed by the maintenance center computer system 424 that develops and maintains a schedule (typically, at specified time slots) for vehicle servicing at the maintenance center 416. The inventory management system 428 is a program that monitors in-stock inventory of replacement parts for the maintenance center 416. A "part" is any device or substance (system, subsystem, component, fluid, and so on) that is part of the vehicle and not cargo. Typically, each part has an associated part number that facilitates ordering and inventory management. The diagnostic program 429 may be the same as the diagnostic program 217 previously described. In this regard, it may be noted that the computer system 416 is capable of manipulating the I/O devices of the vehicle 411 by sending appropriate commands to the control system 1420 of the vehicle 411.

[0181] The web browser 430 allows an operator of the maintenance center computer system 424 to access the information content of the web site provided by the web server 423 of the vehicle 411. Thus, as previously described, the operator can click on various vehicle subsystems or input/output devices, and the web server 423 will receive these inputs and provide the operator with the requested information. The Internet browsing program may be any one of many different types of software from a full scale browser down to a simple browser that is commonly used for Internet enabled wireless phones, depending on how information is presented to the operator.

[0182] The manufacturer 417 is a manufacturer of the vehicles 411-414 and/or a manufacturer of replacement parts for the vehicles 411-414. The manufacturer 417

has a manufacturer computer system 432 which includes an inventory management system 433, a diagnostic program 434, and a web browser 435. The inventory management system 434 is a program that monitors in-stock inventory for the manufacturer 417. The web browser 435 and the diagnostic program 434 may be the same as described in connection with the diagnostic program 429 and the web browser 430 of the maintenance center computer system 424.

[0183] The fleet manager 418 is the entity that owns or leases the vehicles 411-414, for example, a municipality, the military, and so on. The fleet manager 418 has a fleet manager computer system 437 that includes a web browser 438. The web browser 438 allows the fleet manager 418 to monitor the status and position of the vehicle 411 as previously described in connection with the web browser 430.

[0184] The computer systems 422, 424, 432 and 437 of the vehicles 411-414, the maintenance center 416, the manufacturer 417, and the fleet manager 418, respectively, are all connected to the communication network 420. The communication network 420 is preferably the Internet. The Internet is preferred because it is a convenient and inexpensive network that provides worldwide communication capability between the computer systems 422, 424, 432 and 437. Additionally, the Internet permits communication between the on-board computer system 422 and the maintenance center computer system 424 using electronic mail format or other commonly used Internet communication formats. Preferably, security/encryption techniques are used which allow the Internet to be used as a secure proprietary wide area network. A variety of other types of networks may also be used, such as a wireless local area network, a wireless wide area network, a wireless metropolitan area network, a wireless long-haul network, a secure military network, or a mobile telephone network.

[0185] The on-board computer system 422 is preferably connected to the Internet by way of a wireless modem. Preferably, the on-board computer system 422 uses a cellular telephone modem with coverage in the geographic region in which the vehicle 411 operates and capable of establishing a dial-up connection to the Internet by way of a telephone link to an Internet service provider. Other communication networks and devices may be used, such as a satellite link, infrared link, RF link, microwave link, either through the Internet or by way of other secure networks as mentioned above. Additionally, the on-board computer system 422 may use some other form of

custom or commercially available software to connect to the computer systems 424, 432 and 437, especially if an Internet connection is not used.

[0186] Referring now to Figs. 22-23, the operation of the system 410 to order a replacement part and schedule maintenance for the vehicle 411 is illustrated. Figure 22 shows the operation of the on-board computer system 422. Fig. 23 shows the operation of the maintenance center computer system 424 which cooperates with the on-board computer system 422. Referring first to Fig. 22, at step 441, a diagnostic test is performed to measure a vehicle parameter. As previously mentioned, the system 411 is preferably used in connection with the diagnostic system 212 described in connection with Figs. 13-20, and the diagnostic test may be any of the tests described in connection with Figs. 13-20 or other tests.

[0187] Preferably, step 441 is performed continuously throughout normal operation of the vehicle 441. Thus, as the vehicle 411 travels on the highway, for example, vehicle operating conditions are monitored and the tests identified in Table II are performed without operator involvement.

[0188] At step 442, the test control module 215 determines that maintenance is required, for example, by comparing the measured operating parameters to reference values for the operating parameters. The operating parameters may, for example, include temperatures, pressures, electric loads, volumetric flow of material, and so on, as described above. Upper and/or lower reference values are stored in a database or table in the test control module 215. The reference values for the operating parameters may be stored based on values provided by the manufacturer of the vehicle 411 or are set based on information provided by the manufacturer and based on actual usage conditions. In addition, the reference values may be updated periodically when the on-board computer system 422 connects to the appropriate maintenance center computer system 424. If the measured operating parameter is outside an acceptable range as defined by the reference values, then maintenance is required.

[0189] At step 443, when it is determined that an operating parameter is outside an acceptable range at step 442, the diagnostic system 212 fault isolates to a replaceable part. The manner in which step 443 is performed depends on the parameter that is out of range. Many types of vehicle parts wear out regularly, and

the fact that a particular parameter is out of range often has a high correlation with a particular part being in need of replacement. For example, and with reference to Table II, if the measured parameter is battery resistance change, and the battery resistance change is out of range, then this indicates that the battery needs to be replaced. If the measured parameter is starter current, and the starter current is low, then this indicates that the starter needs to be replaced. If the measured parameter is current through an output device (e.g., a light bulb), and no current flows through the output device, then this indicates that the output device needs to be replaced. If the measured parameter is a fluid level, and the fluid level is below a predetermined level as indicated by a fuel gauge, then this indicates that additional fluid is required to replace lost fluid. Additionally, a significant number of routine maintenance items may be identified in this manner. Thus, the diagnostic system 212 preferably monitors actual usage (e.g., distance traveled, engine hours, and so on) to determine when routine maintenance (e.g., a tire change, an oil change) is required, indicating that one or more parts (e.g., one or more tires, or the oil and the oil filter) of the vehicle are in need of replacing. (In this regard, it may be noted that the process of Fig. 22 may also be used even where no replacement part is ordered, for example, to schedule a preventive maintenance checkup based on actual vehicle usage.)

[0190] Further, the I/O states of the input devices 1440 and output devices 1450 may be compared to detect inconsistencies and thereby locate devices that are in need of replacing. For example, if the input state of a particular input device 1440 is inconsistent with I/O status information received from one or more other (possibly, redundant) devices, then this indicates that the particular input device 1440 is in need of replacing. Moreover, the I/O circuitry of the interface modules 1420 provides additional health and operation information regarding the I/O devices 1440 and 1450. For example, if the voltage across a particular input device is zero volts, and the expected input range for that input device is +1.0 volt to +5.0 volts, then this indicates that the input device 1440 is in need of replacement. Alternatively, if a given output device 1450 never draws any power regardless of the perceived output state of the output device 1450, then this indicates that the output device 1450 is in need of replacing. Thus, by testing voltage and current conditions in the I/O circuitry of the interface modules 1420, an indication of particular input devices 1440 or output devices 1450 that are in need of replacing may be obtained.

[0191] In a limited number of circumstances, it is desirable for the fault isolating step 443 to be performed at least partially in response to operator inputs. Specifically, operator inputs are desirable when an out-of-range parameter indicates that maintenance is required, but the parameter (or combination of parameters) that is out-of-range is not highly correlated with failure of a particular part. In this case, then operator inputs may be used in combination with other inputs to identify which part is in need of replacing. For example, the diagnostic system 212 may be able to fault isolate to a limited number of parts or groups of parts which potentially need to be replaced. The parameters that are out of range, along with other diagnostic data and the parts or groups of parts that potentially need to be replaced, are then displayed to the operator using the display 219. The operator may for example be the driver of the vehicle or maintenance personnel assigned to maintain or repair the vehicle. Operator inputs are then acquired which make a final selection of the parts or groups of parts to be replaced based on the operator's professional judgment or other information.

[0192] Additionally, operator input may also be desirable in the case of replacement parts that have a cost which exceeds a predetermined threshold level (e.g., replacement parts that are considered to be particularly expensive). In this case, the results of the fault isolating step 443 are preferably displayed to the operator, and the operator is requested to confirm that the fault isolating step 443 has been performed correctly. In a particularly preferred embodiment, the operator is further requested to provide an identification code (to identify the operator and confirm that the operator has the requisite authority to make such a determination) and/or an authorization code (to provide a paper trail and confirm that any required authorizations for order the replacement part have been received). The on-board computer system 424 then verifies that the identification code identifies an operator having the requisite authority to order such a part and request such maintenance, and/or confirms that the authorization code is valid and therefore any required authorizations for order the replacement part have been received.

[0193] The health and operation information that is used by the diagnostic system 212 to perform step 443 may be derived from a variety of sources. First, as previously noted, the control systems 224-230 have built in test capability and are able to provide health and operation information regarding the respective controlled subsystems 234-240. Additionally, numerous sensors may be located throughout the

vehicle and connected to one of the interface modules 1420. Further, the I/O circuitry of the interface modules 1420 provides additional health and operation information regarding the I/O devices 1440 and 1450 to which it is connected. To the extent that the amount of health and operation information available to the diagnostic system 212 is increased (e.g., through the use of improved built-in test capabilities or the use of additional sensors),. the ability of the diagnostic system 212 to fault isolate will be improved.

[0194] At step 444, which may be performed concurrently with step 443, the diagnostic system 212 identifies the part number of the replacement part required to return the vehicle 411 to operating condition. Thus, if the diagnostic system 212 determines that the battery needs to be replaced at step 443, then at step 444 the diagnostic system identifies the part number of the battery to be replaced. Step 444 is preferably performed using a database that identifies all parts on-board the vehicle 411, including part numbers and pricing information. The data base is preferably located on the on-board computer system 422 and is integrated with the previously-discussed maintenance jacket which is stored in the computer system 422 and which comprises a log of maintenance activities performed on the vehicle 411. In order for the data base to be kept current, the database is updated periodically by establishing an Internet link with the manufacturer computer system 432. Alternatively, the database may be stored at the fleet manager computer system 437 and accessed via network connection over the communication link 420. For example, this is advantageous if the functionality of the fleet manager computer system 437 is combined with the functionality of the maintenance center computer system 424 in a single computer system. In this situation, the inventory management system 428 can maintain inventory levels in a manner that takes into account how many vehicles use a particular part. The inventory management system 428 can also query the diagnostic systems 212 of particular vehicles to assess how soon particular parts may need to be replaced.

[0195] At step 445, after the fault has been isolated and the replacement part has been identified, a request for a replacement part along with a request for maintenance is transmitted to the maintenance center computer system 424. If the parts data base is stored at the on-board computer system 422, then the request for the replacement part may simply comprises a request for a part identified by a particular part number

(e.g., "Battery, part no. 1234"). If the parts data base is stored at the maintenance center computer system 424, then the request for the replacement part simply comprises a request for a new part without specifying a part number. The operator identification code and/or authorization code are preferably also transmitted.

[0196] Step 445 is preferably performed whenever a part is identified that is in need of replacing. However, step 445 may also be performed in delayed fashion after the maintenance center computer system 424 initiates contact with the on-board computer system 422 and queries whether any parts and maintenance are required.

[0197] Referring now also to Fig. 23, Fig. 23 shows the operation of the maintenance center computer system 424 after the parts and maintenance request is transmitted from the on-board computer system 422. At step 451, the maintenance center computer system receives the request for the parts and maintenance request from the on-board computer system 422. At step 452, the maintenance center computer system 424 verifies the authorization for the ordered part. For example, the maintenance center computer system 424 confirms that the identification code identifies an operator having the requisite authority to order such a part and request such maintenance, and/or confirms that the authorization code is valid and therefore any required authorizations for order the replacement part have been received.

[0198] At step 453, the maintenance computer system 424 accesses the inventory management system 428 for the maintenance center 416 to determine if the requested part is available in on-site inventory. For example, for low dollar value or common parts, the part is likely to already be available on-site. For high dollar value or irregular parts, the part may have to be ordered from the manufacturer 417.

[0199] At step 454, assuming the requested part is determined to be not available on-site in step 453, then the maintenance center computer system 424 places an on-line order for the part with the manufacturer computer system 432. When the manufacturer computer system 432 receives the order, it accesses the inventory management system 433. If the part is on-hand at the manufacturer 417, the part can be shipped to the maintenance center for next day delivery. If the part is not on-hand, the manufacturer computer system 432 determines the amount of time until the part will be available (taking into account any backlog of orders). The manufacturer computer system 432 then transmits a message to the maintenance center computer

system 424 confirming the order and indicating an expected delivery date for the part to the maintenance center. This information may, for example, be sent in the form of e-mail message that is received by automatic scheduling program as well as a personal e-mail account associated with a supervisor or manager of the maintenance center 416.

[0200] At step 455, the maintenance center computer system 424 receives the message from the manufacturer computer system 432 confirming the order and indicating the expected delivery date. At step 456, the maintenance center computer system 424 accesses the maintenance scheduler 427 to determine the next available maintenance slot after the replacement part is delivered.

[0201] At step 457, the maintenance center computer system 424 confirms availability of the vehicle 411, for example, by transmitting a message to the fleet management computer system 437 to confirm vehicle availability. Alternatively, a message may be sent to the operator of the vehicle 411 and displayed using the 219 to prompt the operator to confirm vehicle availability (shown as step 446 in Fig. 22). As a further alternative, the vehicle 411 may be programmed with usage scheduling information, so that the vehicle is able to determine whether it is available during a given time slot. If the vehicle 411 is not available during a given time slot, then another time slot is considered.

[0202] At step 458, the maintenance center computer system 424 transmits an order and maintenance scheduling confirmation message to the on-board computer system 422. Referring back to Fig. 22, at step 447, the order and maintenance scheduling confirmation message is then received by the on-board computer system and, at step 448, displayed to the operator of the vehicle 411.

[0203] In some situations, after connecting, the maintenance center computer system 424 may completely control diagnosis of the problem, for example, under the control of an operator at the maintenance center 416. Thus, the operator can execute a diagnostic program that directly manipulates I/O states of the input devices 1440 and output devices 1450, and/or that interfaces with the control systems 224-230 to control a respective one of the systems 234-240. In this regard, it may be noted that, in the preferred embodiment, all electric/electronic devices that are not directly connected to one of the control systems 224-230 are directly connected to one of the

interface modules 1420. Therefore, a remote operator at the maintenance center 416 can have complete control of all electric devices on board the vehicle 411, and can control such things as engine ignition, engine cranking, and so on.

[0204] The maintenance center computer system 424 may also download a diagnostic program that is then used by the on-board computer system 422. Also, diagnostic data can be transmitted to the maintenance center computer system 424 to create a record of the tests performed and routines run for use in diagnosing future problems or for analyzing past problems.

[0205] Referring now to Fig. 24, in another embodiment, the system 400 is used to distribute recall information for the vehicle 411 and to schedule maintenance in connection with the recall. The recall notice information is transmitted from the maintenance center computer system 424 and, at step 441', is received at the on-board computer system 422. At step 442', the on-board computer system 422 confirms the applicability of the recall. For example, the on-board computer system 422 confirms that the vehicle 411 is configured in such a manner that it utilizes the part that is the subject of the recall. Steps 441' and 442' roughly correspond to steps 441-444 in Fig. 22, in as much as both groups of steps identify a part that is in need of replacing. Thereafter, the operation of the on-board computer system 422 and the maintenance center computer system 424 is generally the same as previously described, with the two computer systems 422 cooperating to schedule the vehicle 411 for maintenance to replace the part that is the subject of the recall.

[0206] In an alternative embodiment, the recall information may be transmitted directly from the manufacturer computer system 432 to the on-board computer system 422. For example, if the vehicle 411 is not part of a fleet of vehicles, and may be serviced at any one of a plurality of different repair centers, the recall notice information may be simply displayed to the operator of the vehicle 411 using the display 219. The information sent to the operator preferably includes a notice that the vehicle 411 is the subject of a recall, information regarding compliance such as nearby service centers available to perform the recall maintenance, and other information. The operator then has the option of scheduling maintenance to comply with the recall. However, it is necessary for an operator input to be received (e.g., a key press) indicating that the recall information has been considered in order to remove the recall information from the display 219. When the operator input is received, a message is

transmitted back to the manufacturer computer system 432 confirming that the operator received the recall information. This arrangement allows a manufacturer of the vehicle 411 to verify that the recall information was received by the operator of the vehicle 411, even if the recall information is ultimately ignored.

[0207] The system 410 is also useable for firmware upgrades. Firmware may be updated on a periodic or aperiodic basis any time the on-board computer system 422 and the maintenance center computer system 424 establish communication. For example, the on-board computer system 422 may connect to the maintenance center computer system 424 to order a replacement part. If a certain period of time has expired since the last firmware upgrade then at the time the computer systems connect to order the part, the on-board computer system 422 may check for an available firmware upgrade. Many embodiments for upgrading firmware are within the scope of the present equipment service vehicle system. For example, the operator may initiate the firmware upgrade process or the on-board computer system 422 may initiate the process independent of any other need to connect to the maintenance center computer system 424. Also, there may be situations where the firmware upgrade is sufficiently important that the maintenance center computer system 424 connects to the on-board computer system 422 for the express purpose of upgrading the firmware. Once transferred to the on-board computer system 422, the firmware is then transmitted to and installed by each of the interface modules 1420 within the on-board computer system 422. This arrangement may also be used to install firmware for the control systems 224-230.

[0208] Referring now also to Figs. 25-26, a preferred fleet monitoring, real time mission readiness assessment, and vehicle deployment method is shown. The method shown in Figs. 25-26 is useable to obtain a real time assessment of each vehicle in a fleet of vehicles. This is useful, for example, in the context of a natural disaster or other emergency when it is not known which vehicles are operational, and the locations of the vehicles is not known. Again, by way of example, the method is described in the context of the system 400 of Fig. 21. Figure 25 shows the operation of the fleet management 437. Figure 26 shows the operation of the on-board computer system 422. Although Figs. 25-26 are discussed in the context of the vehicle 411, the process of Figs. 25-26 are preferably performed in connection with all of the vehicles in the fleet.

[0209] Referring first to Fig. 25, at step 475, the fleet management computer system 437 establishes a communication link with the vehicle 411 using the communication network 420. In the context of municipal applications, a cellular telephone modem may be used to connect the vehicle to a secure area of the Internet, allowing the fleet management computer 437 to communicate with the vehicles 411-414 by way of the Internet. In the context of military applications, a secure military network is used to implement the communication network 420. At step 476, a vehicle status report is acquired from the vehicles 411.

[0210] Referring now also to Figure 26, the operation of the on-board computer system 422 of the vehicle 411 to generate such a status report is shown. At step 485, a communication link is established with the fleet management computer system 437. Step 485 corresponds to step 475 in Fig. 25. At steps 486-494, the on-board computer system 422 performs a series of tests that assess the operability of various vehicle subsystems. By testing each of the individual subsystems, an overall assessment of the mission readiness of the vehicle 411-414 is obtained.

[0211] Thus, at step 486, the test control module confirms that the transmission is in neutral and the brakes are locked. Step 486 is performed so that when the ignition is engaged at step 487, it is known that the vehicle will remain stationary. More complete health and operational testing may be performed when the engine is turned on, however, the vehicle may be completely unattended and therefore vehicle movement should be avoided for safety reasons. For example, in the context of military vehicles, in which vehicles may be rendered inoperable if a storage site or other stockpile of equipment and vehicles is bombed, it is desirable for the vehicle health and operation to be ascertained even though no operator is present. Likewise, in the context of municipal applications, in which vehicles may be rendered inoperable in the event of a natural disaster (such as a tornado or hurricane) or a man-made disaster (such as a large scale industrial accident or a terrorist attack), it is again desirable for the vehicle health and operation to be ascertained even though no operator is present.

[0212] At step 487, as previously noted, the ignition is engaged. The ignition input device which receives an input from the operator (in the form of an ignition key turning) is preferably one of the input devices 1440. Therefore, by manipulating the I/O states in the I/O status table 1520, the vehicle 411 is commanded to behave as

though the ignition key is turned even though no operator is in fact present at the vehicle. The ignition key input state can be manipulated remotely in the same manner as any other input state for an input device 1440 connected to an interface module 1420.

[0213] At step 488, the anti-lock brake control system 226 tests the brakes 236. The control system 226 performs built-in self tests to ensure the operability of the control system 226 and of the mechanical components of the brake system 236. If no response is received by the on-board computer system 422 from the brake control system 226, then it is assumed that the brake system 226 has been rendered inoperable. At steps 489, 490, and 491, respectively, the central tire inflation system, the transmission system 238, and the engine system 240 are tested in generally the same manner that the anti-lock brake system 236 is tested, specifically, through the use of built-in self test capabilities. Additionally, the tests set forth above in Table II may also be performed. It should be noted that the systems 234-240 need not be tested one after the other as shown in Fig. 26 but, in practice, may be tested concurrently. Further, in addition to employing the built-in self test capabilities of the control systems 224-230, it may also desirable to employ additional health and operation information that is attainable by way of any sensors that are connected to the interface modules 1420. Information pertaining to the operational health of the systems 234-240, such as whether respective system 234-240 passed or failed particular tests, is then logged.

[0214] In step 492, the interface modules 1420 test individual input devices 1440 and output devices 1450. For example, the input devices 1440 can be tested by ensuring that redundant input sensors provide the same input information, and by ensuring that the input devices provide input signals that are within an expected range. The output devices 1450 may be tested by using input devices 1440 which are feedback sensors to evaluate the response of the output devices 1450 to signals that are applied to the output devices 1450. Additionally, I/O drive circuitry of the interface modules 1420 may be used to determine the current through and/or the voltage across the output devices 1450. Alternatively, separate input devices 1440 may be used which are voltage or current sensors. This information can be used to assess the consumed power by each output device 1450 and determine whether the consumed power is within a predetermined range.

[0215] At step 493, the GPS coordinates of the vehicle 411 are acquired using the GPS receiver 425. At step 494, other I/O status information is acquired and logged from the I/O status table 1520. Preferably, all of the information in the I/O status table 1520 is logged. As a result, the I/O status report contains information regarding such parameters as fuel level. Additionally, in the context of multi-purpose vehicles, information regarding the configuration of the vehicle 411 may be stored in the I/O status table 1520. Therefore, after a natural disaster, it will be known whether a particular vehicle is presently configured with a dump truck variant module, a wrecker variant module, or a snow removal variant module, for example.

[0216] At step 495, the information which logged during steps 487-494 is compiled into the vehicle status report. Of course, step 495 may also be performed concurrently as each of the steps 486-493 is completed. Preferably, during step 495, a summary conclusion is also generated based on the results of the tests performed during steps 487-494. For example, the summary conclusion may be "fully operational" if the results of the tests performed during steps 487-494 determine that all subsystems are at or near a level of full operability, "operational with limited damage" if the test results indicate that one or more subsystems has sustained significant damage but the vehicle is still useful for at least some intended purposes, "inoperable" if the test results indicate that that one or more subsystems has sustained significant damage and the vehicle is not useful for any intended purpose, and "inconclusive" if the tests could not be performed or if the test results provide conflicting information regarding the operability of the vehicle 411. At step 496, the vehicle status report is then transmitted from the on-board computer system 422 to the fleet management computer system 437.

[0217] Referring back to Fig. 25, after the vehicle status report is acquired by the fleet management computer 437, the fleet management computer system 437 displays to an operator the vehicle location information at step 477 and the vehicle health and operation information at step 478. Preferably, steps 477-478 are performed in the following manner. Specifically, the vehicle location, health, and operation information is displayed to the operator of the fleet management computer system 437 using the web browser 438. For example, in the context of a fleet of municipal vehicles, the web browser 438 displays a city map with icons representing the vehicles superimposed on the city map at locations corresponding to the actual

position of the vehicles. The icons are displayed in a manner which is indicative of the level of health and operation of the vehicle. For example, a red icon indicates an inoperable vehicle, a yellow icon indicates a semi-operable vehicle, and a green icon represents a vehicle which is substantially fully operable. Alternatively, only two colors may be used (e.g., green and red), with varying levels of gradations between red and green being used to indicate a percentage level of operability. Further, the displayed icons preferably vary according to the type of vehicle represented. For example, an icon representing a fire truck may be displayed as a small representation of a fire truck, whereas an icon representing a wrecker vehicle may be displayed as a small representation of a wrecker vehicle. In the context of variant vehicles, the variant vehicle may be represented in different ways depending on the type of variant module mounted on the vehicle chassis. In this way, the operator is able to view the city map displayed by the web browser 438 and obtain an immediate overall picture of the real time locations of the operable vehicles available for responding to the natural disaster. Likewise, in military applications, a battlefield commander is able to view a map of the battlefield and obtain an immediate overall picture of the locations of the operable military vehicles. Again, different types of military vehicles may be represented using different icons. Further, in both military and municipal contexts, to obtain additional information, the operator of the fleet management computer system 437 can click on the iconic representation of a particular vehicle to obtain additional information as previously described.

[0218] At step 479, the fleet management computer system 437 acquires operator commands for vehicle deployment. For example, in military applications, a commander can control troop movements by clicking on particular vehicles and dragging the vehicles on the screen to new locations on the display of the battlefield map. When the operator clicks on a particular vehicle and moves the vehicle to a new location on the battlefield or city map, the new location of the vehicle on the map is converted to GPS coordinates, and the new GPS coordinates are transmitted at step 480 to the vehicle as part of a command from the operator to move the vehicle to the new location. In similar fashion, in municipal applications, a fire chief or dispatcher can cause fire trucks to be deployed to specified locations by clicking and dragging the icon to the desired location on the city map. Once the icon is dragged to the new location, a shadow icon is displayed at the new location until the vehicle reaches the commanded position, allowing the operator of the fleet management computer system

437 to know the actual vehicle position as well as the vehicle's commanded position. When the vehicle reaches its commanded position, the shadow icon is no longer displayed.

[0219] As will be appreciated, various combinations of the above-described features have already been described by way of example. However, as will be appreciated, additional combinations are possible. For example, various types of equipment service vehicles have been described, including fire fighting vehicles, mixing vehicles, snow removal vehicles, refuse handling vehicles, wrecker vehicles, and various types of military vehicles. All of the features described in connection with one of these vehicles may also be used in connection with any of the remaining types of vehicles.

[0220] Referring now to Fig. 27, owners of equipment service vehicles often devise particular routes or other practices which are designed to enhance safety of the vehicle and the general public while maintaining overall efficiency. For example, the owner of the vehicle may have a certain route laid out with a pre-determined number of pickups and deliveries, which the operator of the vehicle can accomplish in a reasonable amount of time without driving the vehicle at an excessive speed or in an otherwise unsafe manner. Given that these routes have been laid out, it is often desirable to have a way of ensuring that the driver conforms to these routes. Fig. 27 is a flowchart showing the operation of the system 410 to detect non-conformance to a predetermined route.

[0221] At step 511 the GPS receiver 425 acquires GPS coordinates for the vehicle 411. At step 512, the GPS coordinates are compared with coordinates of travel path waypoints. Preferably, either the on-board computer system 422 or the fleet management computer system 437 includes a map of the predetermined travel paths (or a series of predetermined travel paths for different tasks). The map of the predetermined travel path is defined by a series of waypoints which in turned are a defined by a GPS coordinates for specific locations along the travel path. The travel path waypoints may be spaced at any distance; however, vehicle path monitoring will be more accurate to the extent the waypoints are closer together. Waypoint manager software may be used to define travels paths and download waypoints for the travel paths into the on-board computer system 422 or the fleet management computer system 437.

[0222] If the comparing step 512 is performed at the on-board computer system 422, then the waypoints are loaded into the on-board computer system 422. If the comparing step 512 is performed at the fleet management computer system 437, then the GPS coordinates acquired during step 511 are transmitted to the fleet management computer system 437 by way of the communication network 420. The advantage of performing the comparison at the vehicle is that it eliminates the need for constant communication between the vehicle and the dispatch station. The advantage of having the comparison performed at the dispatch station is that it ensures that the dispatch station is constantly updated with the vehicle position, making real time remote monitoring possible.

[0223] At step 513, the difference between the actual GPS coordinates with the nearest travel waypoint is compared with a pre-determined amount. If the difference is greater than a pre-determined amount, then this indicates that the operator has deviated from the pre-determined travel path. Each waypoint is provided with permissible lateral and longitudinal deviation values. Alternatively, single value may be used for simplicity. If the deviation is more than a pre-determined amount, then an alert message is sent to the operator of the dispatcher display at step 514.

[0224] If the difference is less than a pre-determined amount, then the distance between stored waypoints is computed (step 515) and the expected travel distance since the last waypoint is computed (step 516). Then, at step 517, it is determined whether the vehicle is progressing at an acceptable rate. This is used to determine, for example, whether the vehicle is on the side of the road. For example, the driver may have stopped the vehicle and, therefore, still on the travel path, but the driver is not progressing at an acceptable rate. By providing real time updates to the dispatcher, the dispatcher can immediately contact the driver to ascertain the source of the problem. Additionally, the dispatcher can make a determination as to whether another vehicle should be used to complete the driver's route.

[0225] If the driver is still on the route and is progressing at an acceptable rate, then everything appears to be in order and the current position, time, and speed are logged at step 518. The process of Fig. 27 is repeated at regular intervals. Assuming vehicle position monitoring is performed by the fleet management computer 437, it is possible to construct a map showing the positions of the vehicle 411 throughout the day. Thus, as the driver operates the vehicle, the position of the vehicle is logged at

different times. Based on vehicle position as a function of time, a map is constructed showing the vehicle's position over time. Additionally, it is possible to log all of the I/O status information throughout the day. Thus, a complete picture of vehicle utilization of the course of a day (or other time period) may be obtained. Additionally, vehicle parameters may be monitored in real time to diagnose equipment malfunctions, click on the vehicle to obtain additional information. For example, vehicle loading may be ascertained to determine whether the vehicle 411 has spare capacity.

[0226] Throughout the specification, numerous advantages of preferred embodiments have been identified. It will be understood of course that it is possible to employ the teachings herein so as to without necessarily achieving the same advantages. Additionally, although many features have been described in the context of a vehicle control system comprising multiple modules connected by a network, it will be appreciated that such features could also be implemented in the context of other hardware configurations. Further, although various figures depict a series of steps which are performed sequentially, the steps shown in such figures generally need not be performed in any particular order. For example, in practice, modular programming techniques are used and therefore some of the steps may be performed essentially simultaneously. Additionally, some steps shown may be performed repetitively with particular ones of the steps being performed more frequently than others. Alternatively, it may be desirable in some situations to perform steps in a different order than shown.

[0227] Many other changes and modifications may be made to the present invention without departing from the spirit thereof.

1. A system comprising:

(A) an equipment service vehicle including

(1) a power source,

(2) a power transmission link,

(3) a plurality of input devices,

(4) a plurality of output devices,

(5) an on-board computer system including a plurality of microprocessor-based interface modules and a communication network, the plurality of interface modules being coupled to the power source by way of the power transmission link, the plurality of interface modules being interconnected to each other by way of the communication network, each of the plurality of interface modules being coupled to respective ones of the plurality of input devices and the plurality of output devices by way of respective dedicated communication links, and the on-board computer system storing I/O status information for the plurality of input devices and the plurality of output devices;

(B) an off-board computer system,

wherein the on-board computer system transmits at least some of the I/O status information by way of a wireless radio-frequency communication link to the off-board computer system.

2. The system according to claim 1, further including a web server and a web browser, the web browser being provided by the off-board computer system, and wherein the I/O status information is posted to a web site maintained by the web server and accessible by the web browser, the information content of the vehicle-based web site being provided at least in part by the plurality of interface modules and including the I/O status information for the plurality of input devices and the plurality of output devices.

3. The system according to claim 2, wherein the web browser displays a representation of the equipment service vehicle to an operator of the web browser, and wherein the web server provides the web browser with I/O status information

pertaining to specific ones of the input and output devices in response to the web browser receiving inputs from the operator of the web browser clicking on representations of the specific ones of the input and output devices.

4. The system according to claim 3, wherein the web server is provided by the on-board computer system.

5. The system according to claim 3, wherein the web server is provided by an additional off-board computer system, and wherein the on-board computer system posts information to the additional off-board computer system.

6. The system according to claim 1, wherein the on-board computer system stores a vehicle maintenance record, the vehicle maintenance record comprising a descriptive log of maintenance activities performed on the vehicle; and wherein vehicle maintenance record is also provided as information content made available to the web browser by the web server.

7. The system according to claim 1, wherein the equipment service vehicle further includes

(1) an engine system, the engine system including an engine and an electronic engine control system that is coupled to the engine and to the communication network, the electronic engine control system controlling the engine and transmitting information pertaining to the health and operation of the engine on the communication network;

(2) a transmission system, the transmission system including a transmission and an electronic transmission control system, the electronic transmission control system controlling the transmission and transmitting information pertaining to the health and operation of the transmission on the communication network; and

wherein the health and operation information from the engine system and the transmission is also provided as information content made available to the web browser by the web server.

8. The system according to claim 1, wherein the on-board computer system is capable of receiving commands from the off-board computer system and

adjusting output states of individual ones of the plurality of output devices in response to the commands, thereby allowing the off-board computer system to directly manipulate the output states of the plurality of output devices.

9. The system according to claim 1, wherein the wireless RF communication link connects the equipment service vehicle to the Internet, and the I/O status information is transmitted by way of the Internet.

10. The system according to claim 1,

wherein each of the plurality of interface modules broadcasts I/O status information pertaining to I/O states of the respective input and output devices the interface modules is connected to each of the remaining interface modules; and

wherein each of the plurality of interface modules maintains an I/O status table at each of the interface modules, the I/O status table storing I/O status information for the plurality of input devices and the plurality of output devices.

11. The system according to claim 1, wherein the plurality of interface modules being distributed throughout the vehicle, and each respective interface module is locally disposed with respect to the respective input and output devices to which the respective interface module is coupled, so as to permit, by way of the respective dedicated communication link, distributed data collection from the respective input devices to the respective interface module and distributed power distribution from the respective interface module to the respective output devices.

12. A system comprising:

(A) a fleet of equipment service vehicles, each vehicle in the fleet of vehicles comprising

(1) a power source,

(2) a power transmission link,

(3) a plurality of input devices,

(4) a plurality of output devices,

(5) an on-board computer system including a plurality of microprocessor-based interface modules and a communication network, the plurality of interface modules being coupled to the power source by way of the power transmission link, the plurality of interface modules being

interconnected to each other by way of the communication network, each of the plurality of interface modules being coupled to respective ones of the plurality of input devices and the plurality of output devices by way of respective dedicated communication links, and the on-board computer system storing I/O status information for the plurality of input devices and the plurality of output devices;

(B) an off-board computer system, the off-board computer system being capable of being connected to each vehicle in the fleet of vehicles by way of a wireless radio-frequency communication network, the off-board computer system being capable of generating a report that compares utilization information for each of the plurality of vehicles.

13. The system according to claim 12, wherein the report compares distance traveled by each of the vehicles in the fleet of equipment service vehicles.

14. The system according to claim 12, wherein the report compares engine utilization time of the vehicles in the fleet of equipment service vehicles.

15. The system according to claim 12, wherein the report compares on-site time of the vehicles in the fleet of equipment service vehicles.

16. The system according to claim 12, wherein the vehicle comprises a plurality of vehicle subsystems, and groups of output devices are compared to indicate relative usage of particular vehicle subsystems.

17. The system according to claim 12, wherein the plurality of interface modules being distributed throughout the vehicle, and each respective interface module is locally disposed with respect to the respective input and output devices to which the respective interface module is coupled, so as to permit, by way of the respective dedicated communication link, distributed data collection from the respective input devices to the respective interface module and distributed power distribution from the respective interface module to the respective output devices.

18. A system comprising:

(A) an equipment service vehicle including

(1) a power source,

(2) a power transmission link,

(3) a plurality of input devices,

(4) a plurality of output devices,

(5) a communication network, and

(6) an on-board computer system including a plurality of microprocessor-based interface modules, the plurality of interface modules being coupled to the power source by way of the power transmission link, the plurality of interface modules being interconnected to each other by way of the communication network, each of the plurality of interface modules being coupled to respective ones of the plurality of input devices and the plurality of output devices by way of respective dedicated communication links; and

(B) an off-board computer system;

wherein the off-board computer system transmits test commands to the on-board computer system, the test commands being transmitted from the off-board computer system to the on-board computer system by way of a wireless radio-frequency communication link;

wherein the on-board computer system performs tests on the vehicle in response to the test commands from the off-board computer system;

wherein the on-board computer system receives the health and operation information in response to the tests being performed, the health and operation information indicating that the equipment service vehicle has a part in need of replacing; and

wherein the on-board communication transmits the health and operation information to the off-board computer system by way of the wireless radio-frequency communication link.

19. The method according to claim 18, wherein the plurality of input devices include a plurality of operator input devices, the plurality of operator input devices.

20. The method according to claim 18, wherein vehicle comprises a plurality of vehicle subsystems, and groups of output devices are compared to indicate relative usage of particular vehicle subsystems.

21. The system according to claim 18, wherein usage of different variant modules is compared.

22. The system according to claim 18, wherein the plurality of interface modules being distributed throughout the vehicle, and each respective interface module is locally disposed with respect to the respective input and output devices to which the respective interface module is coupled, so as to permit, by way of the respective dedicated communication link, distributed data collection from the respective input devices to the respective interface module and distributed power distribution from the respective interface module to the respective output devices.

23. A system comprising:

(A) an equipment service vehicle including

(1) a power source,

(2) a power transmission link,

(3) a plurality of input devices,

(4) a plurality of output devices,

(5) a communication network, and

(6) an on-board computer system including a plurality of microprocessor-based interface modules, the plurality of interface modules being coupled to the power source by way of the power transmission link, the plurality of interface modules being interconnected to each other by way of the communication network, each of the plurality of interface modules being coupled to respective ones of the plurality of input devices and the plurality of output devices by way of respective dedicated communication links; and

(B) an off-board computer system, the off-board computer system being capable of being connected to each vehicle in the fleet of vehicles by way of a wireless radio-frequency communication

network, and wherein the off-board computer system transmits a firmware upgrade to the on-board computer system.

24. The system according to claim 23, wherein the equipment service vehicle periodically accesses an off-board computer and performs the firmware upgrade automatically.

25. The system according to claim 23, wherein the firmware upgrade is transmitted to each of the individual interface modules, which then install the firmware upgrade.

26. The system according to claim 23, wherein the plurality of interface modules being distributed throughout the vehicle, and each respective interface module is locally disposed with respect to the respective input and output devices to which the respective interface module is coupled, so as to permit, by way of the respective dedicated communication link, distributed data collection from the respective input devices to the respective interface module and distributed power distribution from the respective interface module to the respective output devices.

27. A system comprising:

(A) a fleet of vehicles, each vehicle in the fleet of vehicles comprising

(1) a power source,

(2) a power transmission link,

(3) a plurality of input devices,

(4) a plurality of output devices,

(5) an on-board computer system including a plurality of microprocessor-based interface modules and a communication network, the plurality of interface modules being coupled to the power source by way of the power transmission link, the plurality of interface modules being interconnected to each other by way of the communication network, each of the plurality of interface modules being coupled to respective ones of the plurality of input devices and the plurality of output devices by way of respective dedicated communication links, the

plurality of interface modules being distributed throughout the vehicle;

(B) an off-board computer system, the off-board computer system being capable of being connected to each vehicle in the fleet of vehicles by way of a wireless radio-frequency communication network, the off-board computer system being capable of sending commands to the on-board computer system of each of the vehicles to test output devices of the equipment service vehicle by manipulating the output devices on the equipment service vehicle.

28. The system according to claim 27, wherein the off-board computer system is capable of sending commands to test output devices on a variant module.

29. A system comprising:

(A) a fleet of vehicles, each vehicle in the fleet of vehicles comprising

(1) a power source,

(2) a power transmission link,

(3) a plurality of input devices,

(4) a plurality of output devices,

(5) an on-board computer system including a plurality of microprocessor-based interface modules and a communication network, the plurality of interface modules being coupled to the power source by way of the power transmission link, the plurality of interface modules being interconnected to each other by way of the communication network, each of the plurality of interface modules being coupled to respective ones of the plurality of input devices and the plurality of output devices by way of respective dedicated communication links, the plurality of interface modules being distributed throughout the vehicle, and each respective interface module being locally disposed with respect to the respective input and output devices to which the respective interface module is

coupled so as to permit, by way of the respective dedicated communication link, distributed data collection from the respective input devices to the respective interface module and distributed power distribution from the respective interface module to the respective output devices, and the on-board computer system storing I/O status information for the plurality of input devices and the plurality of output devices;

(B) an off-board computer system, the off-board computer system being capable of being connected to each vehicle in the fleet of vehicles by way of a wireless radio-frequency communication network, the off-board computer system being capable of sending commands to the on-board computer system of each of the vehicles to test output devices of the equipment service vehicle by manipulating output devices on the equipment service vehicle.

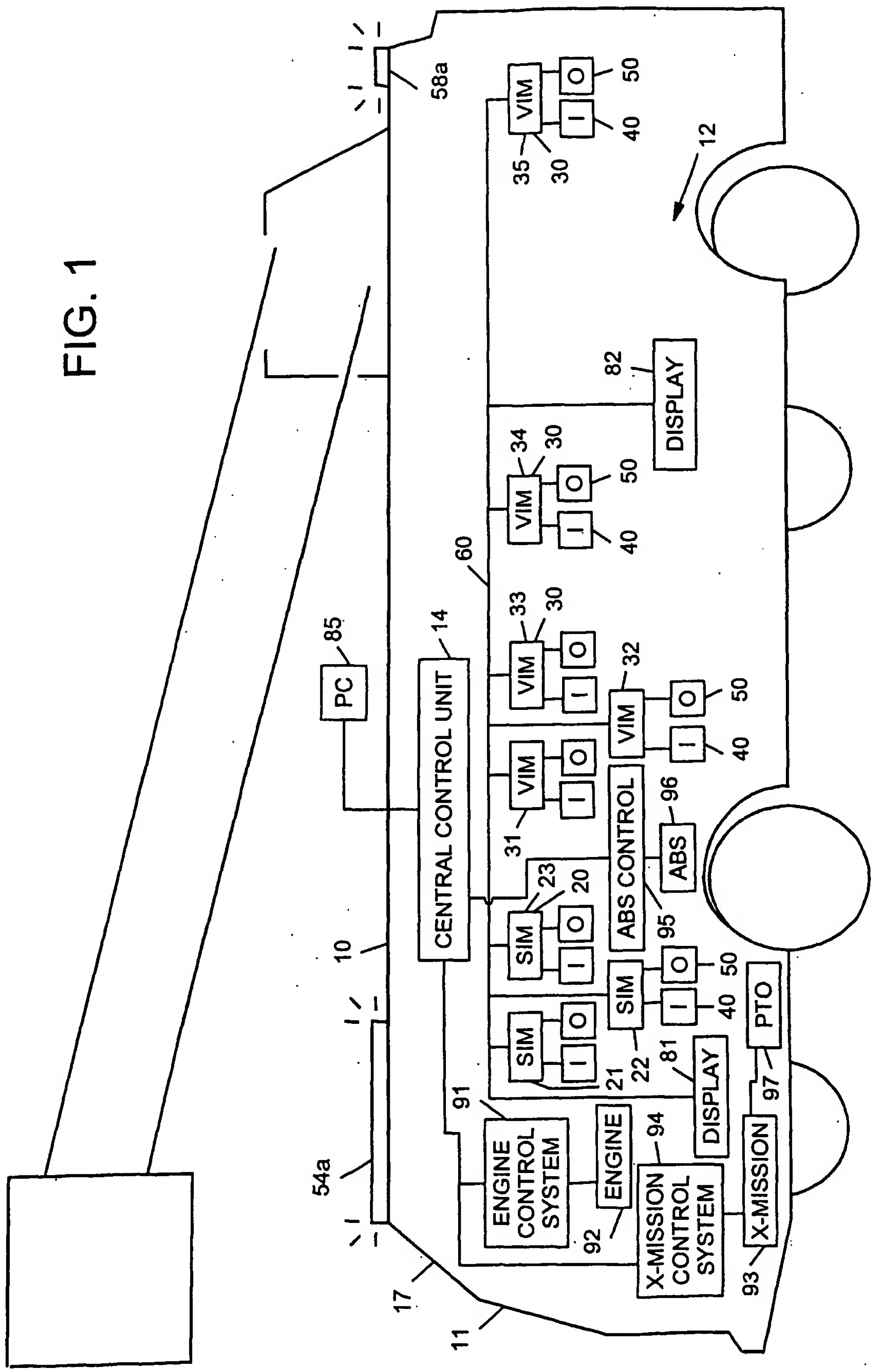

CENTRAL CONTROL UNIT
PC
VIM
SIM
I
O
DISPLAY
ABS CONTROL
ABS
PTO
ENGINE CONTROL SYSTEM
ENGINE
X-MISSION CONTROL SYSTEM
X-MISSION
10
11
12
14
17
20
21
22
23
30
31
32
33
34
35
40
50
54a
58a
60
81
82
85
91
92
93
94
95
96
97

FIG. 1

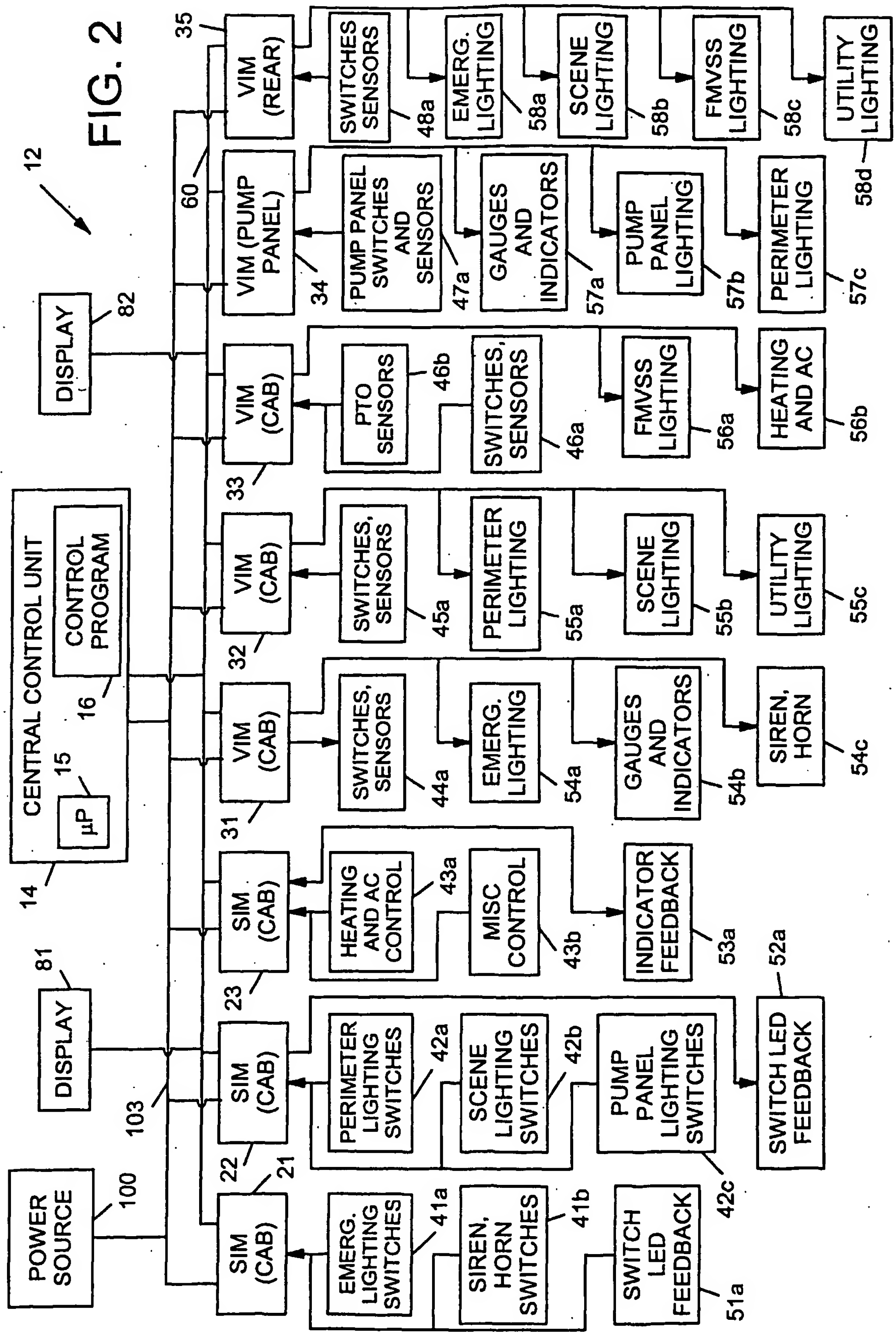

12
CENTRAL CONTROL UNIT
μP
15
CONTROL PROGRAM
16
14
DISPLAY
82
DISPLAY
81
POWER SOURCE
100
103
60
SIM (CAB)
21
SIM (CAB)
22
SIM (CAB)
23
VIM (CAB)
31
VIM (CAB)
32
VIM (CAB)
33
VIM (PUMP PANEL)
34
VIM (REAR)
35
EMERG. LIGHTING SWITCHES
41a
SIREN, HORN SWITCHES
41b
SWITCH LED FEEDBACK
51a
PERIMETER LIGHTING SWITCHES
42a
SCENE LIGHTING SWITCHES
42b
PUMP PANEL LIGHTING SWITCHES
42c
SWITCH LED FEEDBACK
52a
HEATING AND AC CONTROL
43a
MISC CONTROL
43b
INDICATOR FEEDBACK
53a
SWITCHES, SENSORS
44a
EMERG. LIGHTING
54a
GAUGES AND INDICATORS
54b
SIREN, HORN
54c
SWITCHES, SENSORS
45a
PERIMETER LIGHTING
55a
SCENE LIGHTING
55b
UTILITY LIGHTING
55c
PTO SENSORS
46b
SWITCHES, SENSORS
46a
FMVSS LIGHTING
56a
HEATING AND AC
56b
PUMP PANEL SWITCHES AND SENSORS
47a
GAUGES AND INDICATORS
57a
PUMP PANEL LIGHTING
57b
PERIMETER LIGHTING
57c
SWITCHES SENSORS
48a
EMERG. LIGHTING
58a
SCENE LIGHTING
58b
FMVSS LIGHTING
58c
UTILITY LIGHTING
58d

FIG. 2

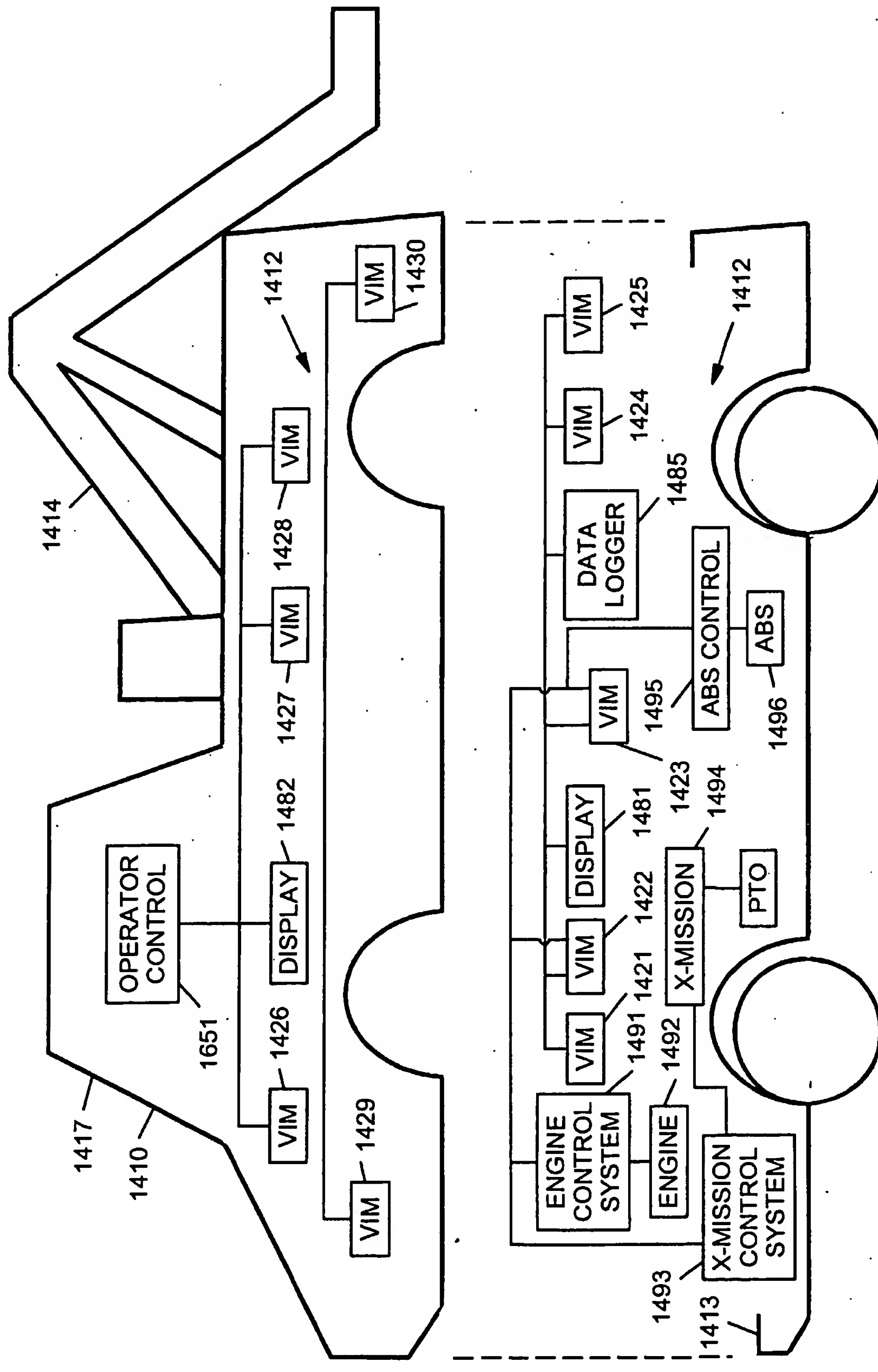

1414
1412
VIM
1430
VIM
1428
VIM
1427
OPERATOR CONTROL
DISPLAY
1482
1651
VIM
1426
VIM
1429
1417
1410
VIM
1425
1412
VIM
1424
DATA LOGGER
1485
ABS CONTROL
ABS
1496
VIM
1495
1423
DISPLAY
1481
1494
X-MISSION
PTO
VIM
1422
VIM
1421
1491
ENGINE CONTROL SYSTEM
ENGINE
1492
X-MISSION CONTROL SYSTEM
1493
1413

FIG. 3

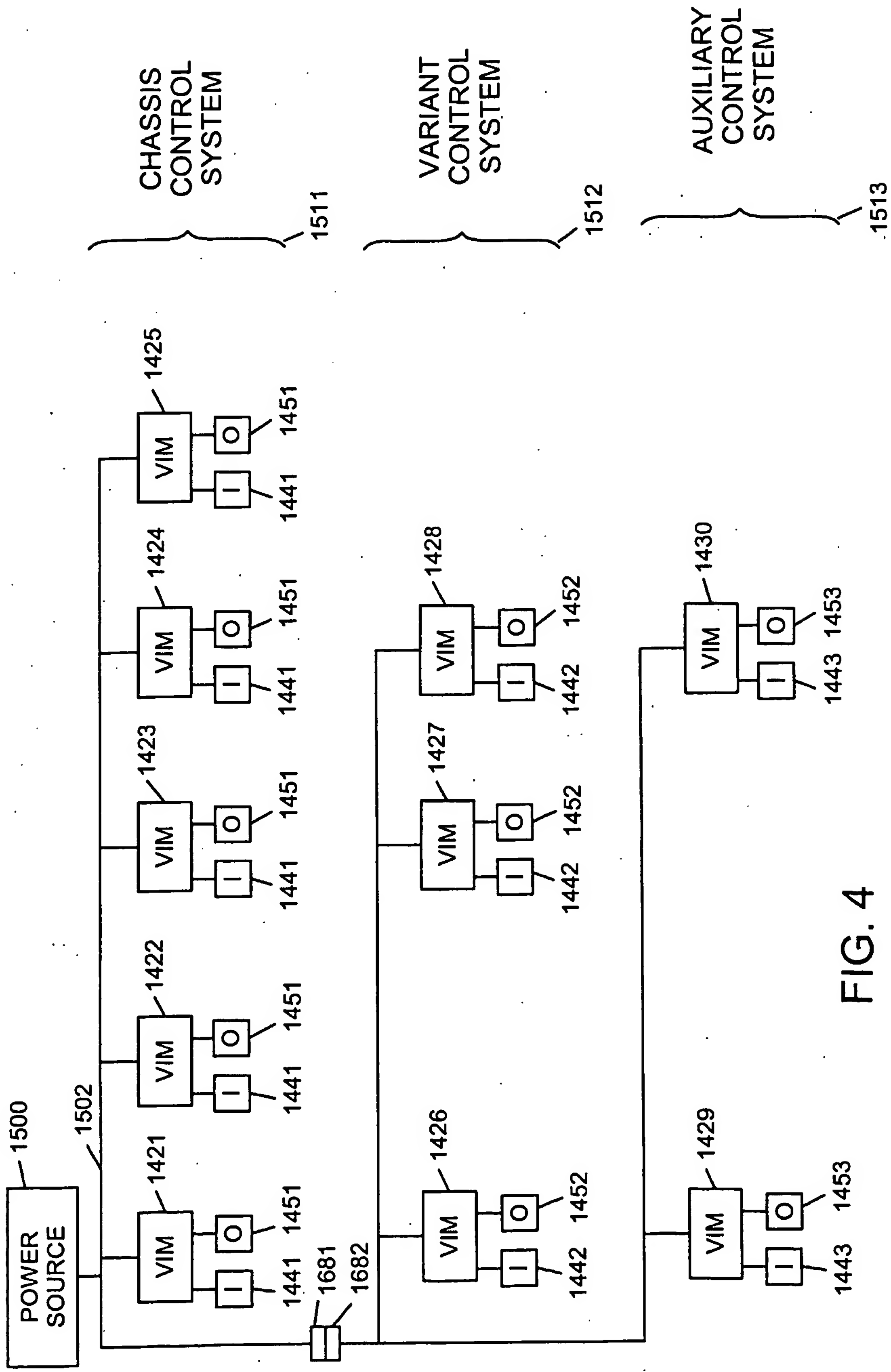

CHASSIS CONTROL SYSTEM
1511
VARIANT CONTROL SYSTEM
1512
AUXILIARY CONTROL SYSTEM
1513
POWER SOURCE
1500
1502
VIM
1421
1422
1423
1424
1425
1426
1427
1428
1429
1430
I
O
1441
1451
1442
1452
1443
1453
1681
1682

FIG. 4

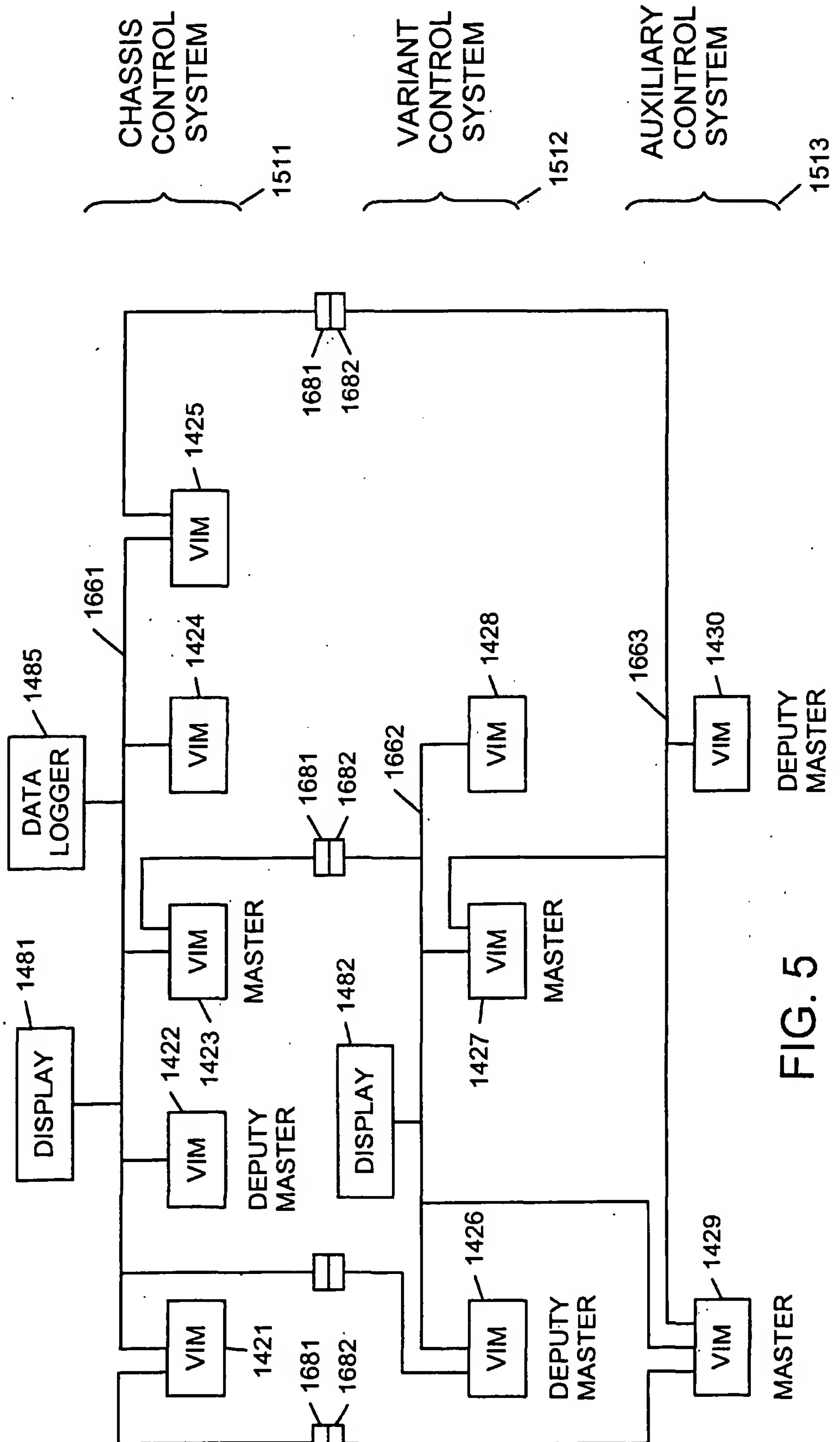

CHASSIS CONTROL SYSTEM
1511
VARIANT CONTROL SYSTEM
1512
AUXILIARY CONTROL SYSTEM
1513
DATA LOGGER
1485
DISPLAY
1481
DISPLAY
1482
VIM
1421
1422
1423
1424
1425
1426
1427
1428
1429
1430
MASTER
DEPUTY MASTER
1661
1662
1663
1681
1682

FIG. 5

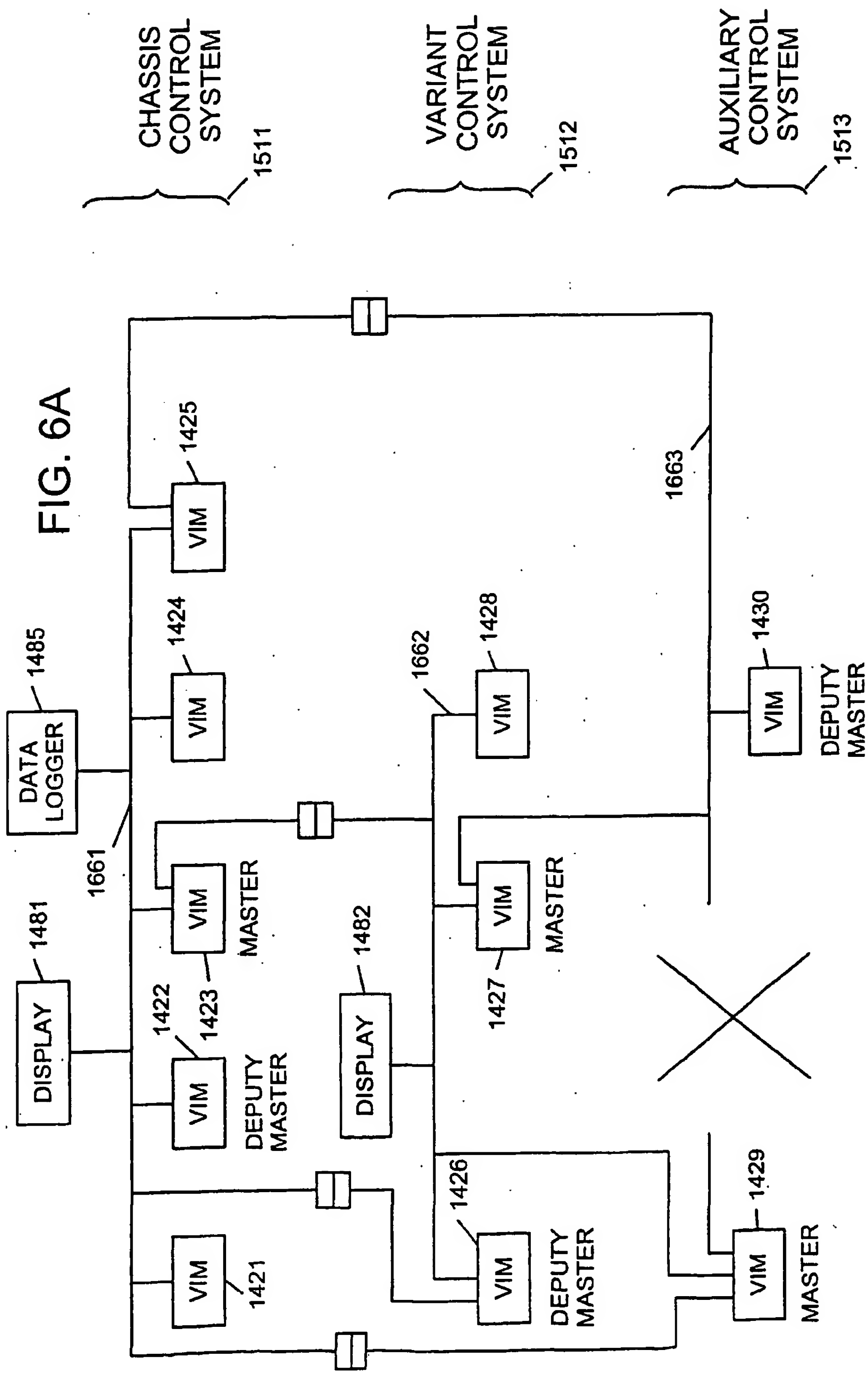

CHASSIS CONTROL SYSTEM
1511
VARIANT CONTROL SYSTEM
1512
AUXILIARY CONTROL SYSTEM
1513
DATA LOGGER
1485
DISPLAY
1481
1661
VIM
1425
VIM
1424
VIM
MASTER
1423
1422
VIM
DEPUTY MASTER
VIM
1421
DISPLAY
1482
1662
VIM
1428
VIM
MASTER
1427
VIM
1426
DEPUTY MASTER
1663
VIM
1430
DEPUTY MASTER
VIM
1429
MASTER

FIG. 6A

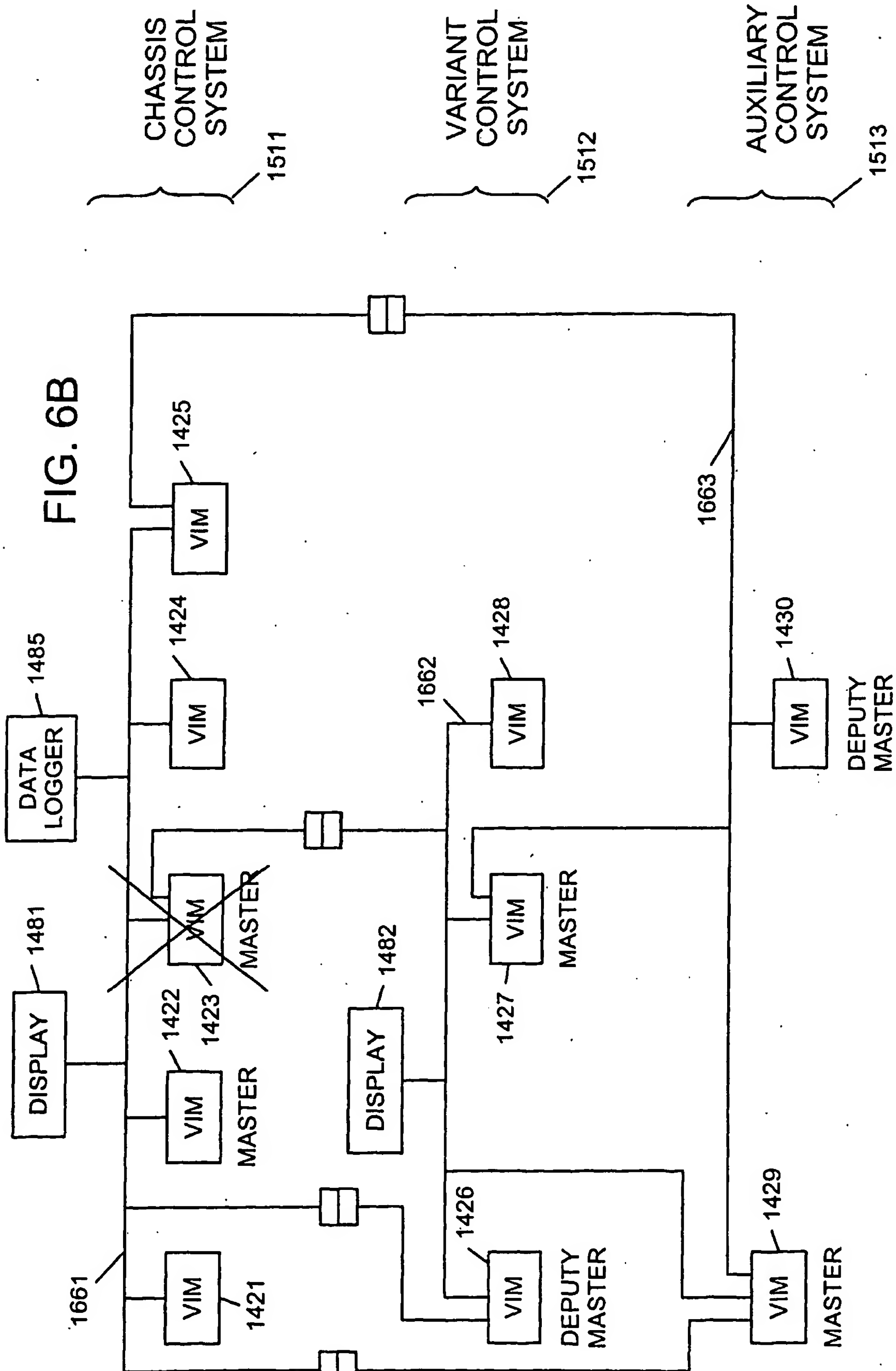

CHASSIS CONTROL SYSTEM
1511
VARIANT CONTROL SYSTEM
1512
AUXILIARY CONTROL SYSTEM
1513
1425
VIM
1663
1485
DATA LOGGER
1424
VIM
1428
VIM
1662
1430
VIM
DEPUTY MASTER
1481
DISPLAY
VIM
MASTER
1422
1423
1482
DISPLAY
VIM
MASTER
1427
VIM
MASTER
1426
VIM
DEPUTY MASTER
1429
VIM
MASTER
1661
VIM
1421

FIG. 6B

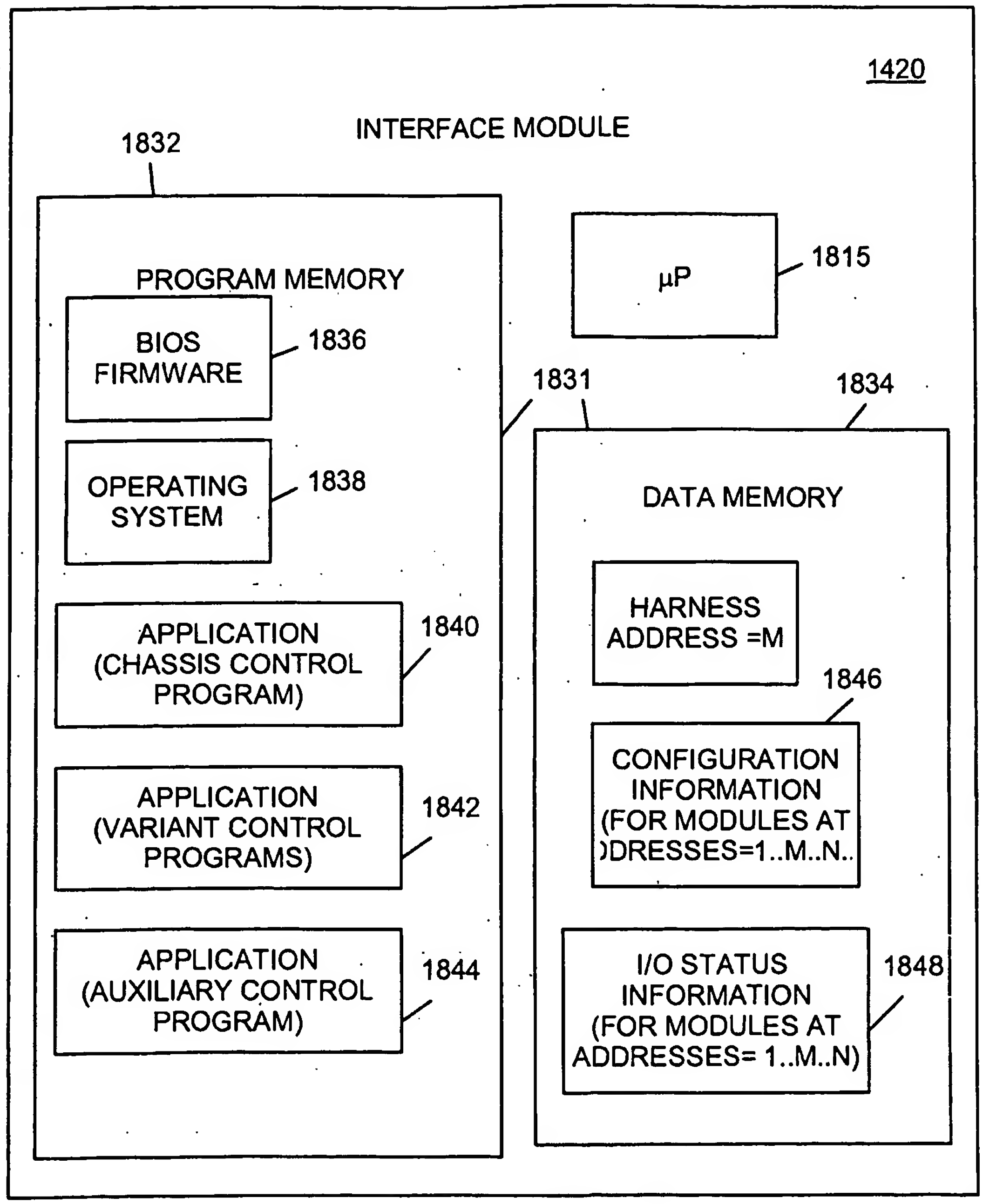

1420
INTERFACE MODULE
1832
PROGRAM MEMORY
BIOS
FIRMWARE
1836
OPERATING
SYSTEM
1838
APPLICATION
(CHASSIS CONTROL
PROGRAM)
1840
APPLICATION
(VARIANT CONTROL
PROGRAMS)
1842
APPLICATION
(AUXILIARY CONTROL
PROGRAM)
1844
µP
1815
1831
1834
DATA MEMORY
HARNESS
ADDRESS =M
1846
CONFIGURATION
INFORMATION
(FOR MODULES AT
)DRESSES=1..M..N..
I/O STATUS
INFORMATION
(FOR MODULES AT
ADDRESSES= 1..M..N)
1848

FIG. 7

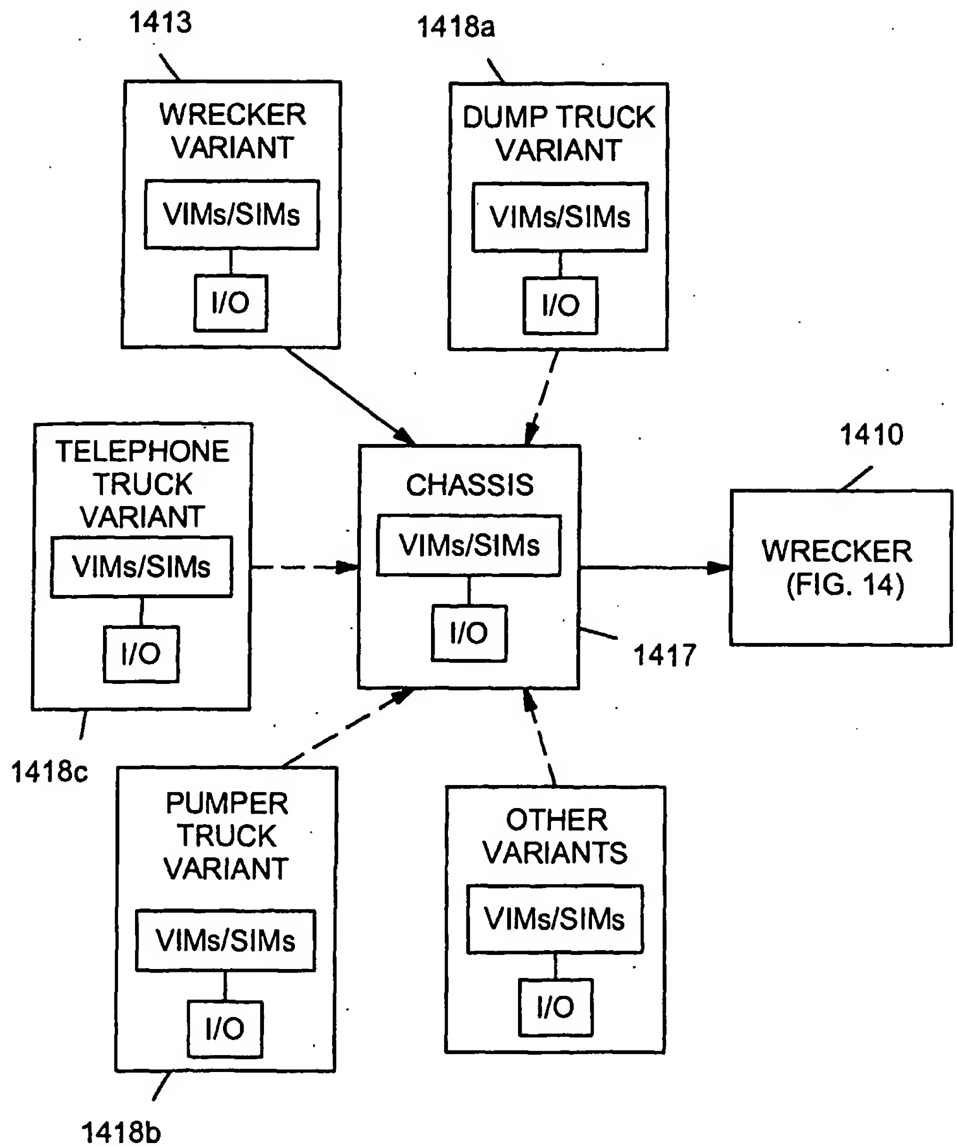

1413
1418a
WRECKER VARIANT
VIMs/SIMs
I/O
DUMP TRUCK VARIANT
VIMs/SIMs
I/O
TELEPHONE TRUCK VARIANT
VIMs/SIMs
I/O
CHASSIS
VIMs/SIMs
I/O
1410
WRECKER (FIG. 14)
1417
1418c
PUMPER TRUCK VARIANT
VIMs/SIMs
I/O
OTHER VARIANTS
VIMs/SIMs
I/O
1418b

FIG. 8

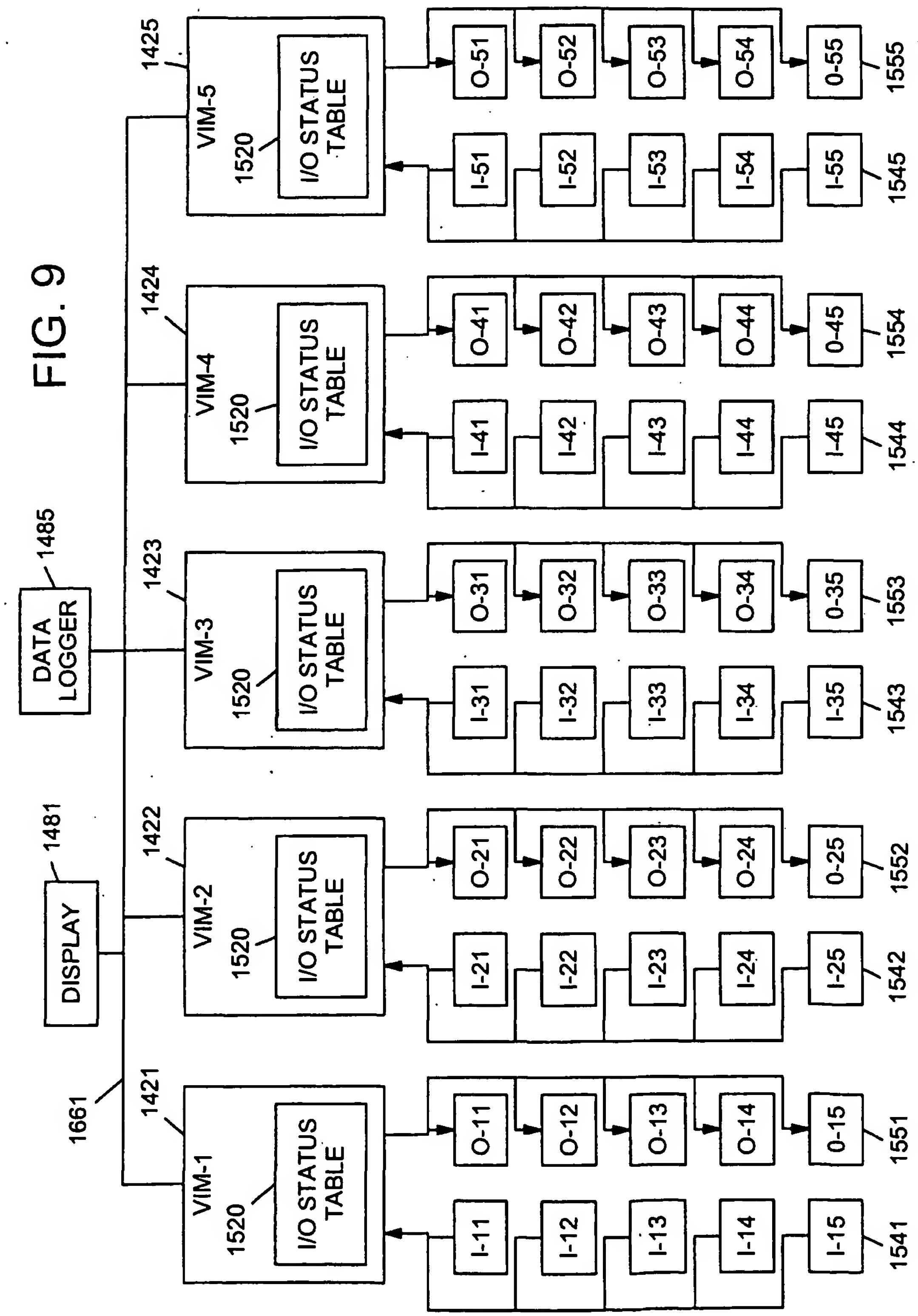

DATA LOGGER
1485
DISPLAY
1481
1661
VIM-1
VIM-2
VIM-3
VIM-4
VIM-5
1421
1422
1423
1424
1425
1520
I/O STATUS TABLE
I-11
I-12
I-13
I-14
I-15
O-11
O-12
O-13
O-14
0-15
1541
1551
I-21
I-22
I-23
I-24
I-25
O-21
O-22
O-23
O-24
0-25
1542
1552
I-31
I-32
I-33
I-34
I-35
O-31
O-32
O-33
O-34
0-35
1543
1553
I-41
I-42
I-43
I-44
I-45
O-41
O-42
O-43
O-44
0-45
1544
1554
I-51
I-52
I-53
I-54
I-55
O-51
O-52
O-53
O-54
0-55
1545
1555

FIG. 9

1520

I-11	I-12	I-13	I-14	I-15	IM-11	O-11	O-12	O-13
O-14	O-15	I-21	I-22	I-23	I-24	I-25	IM-21	IM-22
O-21	O-22	O-23	O-24	O-25	I-31	I-32	I-33	I-34
I-35	O-31	O-32	O-33	O34	O-35	I-41	I-42	I-43
I-44	I-45	IM-41	O41	O-42	O-43	O-44	O-45	I-51
I-52	I-53	I-54	I-55	O-51	O-52	O-53	O-54	O-55

FIG. 10

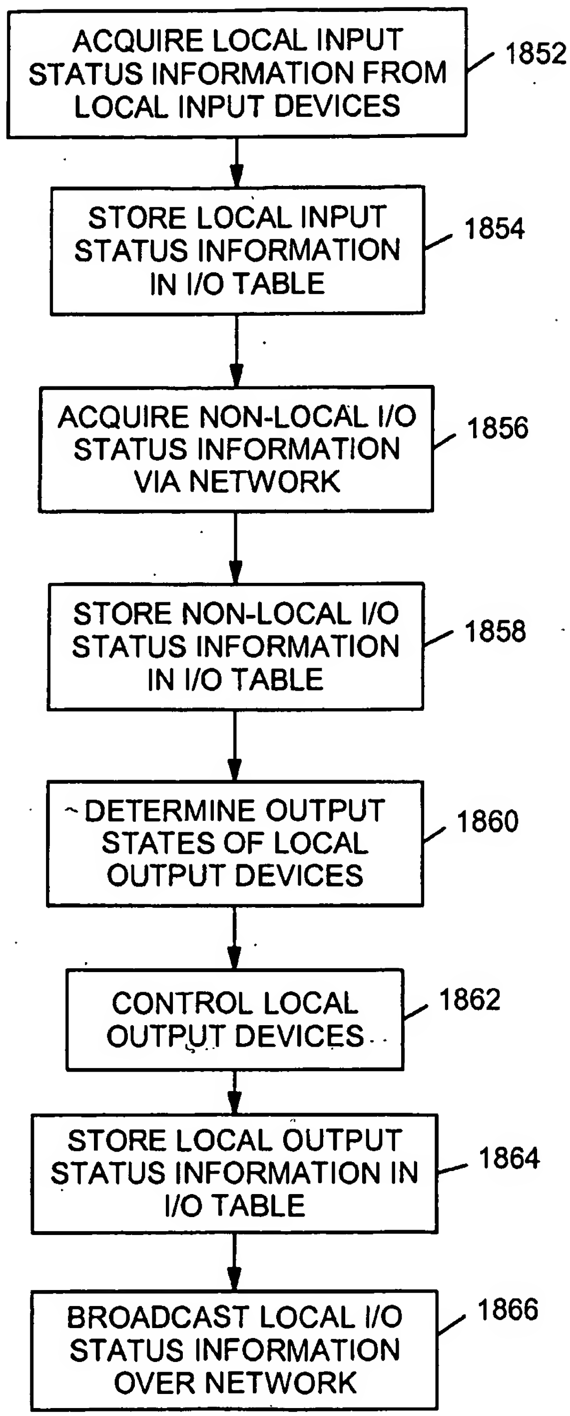

ACQUIRE LOCAL INPUT STATUS INFORMATION FROM LOCAL INPUT DEVICES
1852
STORE LOCAL INPUT STATUS INFORMATION IN I/O TABLE
1854
ACQUIRE NON-LOCAL I/O STATUS INFORMATION VIA NETWORK
1856
STORE NON-LOCAL I/O STATUS INFORMATION IN I/O TABLE
1858
DETERMINE OUTPUT STATES OF LOCAL OUTPUT DEVICES
1860
CONTROL LOCAL OUTPUT DEVICES
1862
STORE LOCAL OUTPUT STATUS INFORMATION IN I/O TABLE
1864
BROADCAST LOCAL I/O STATUS INFORMATION OVER NETWORK
1866

FIG. 11

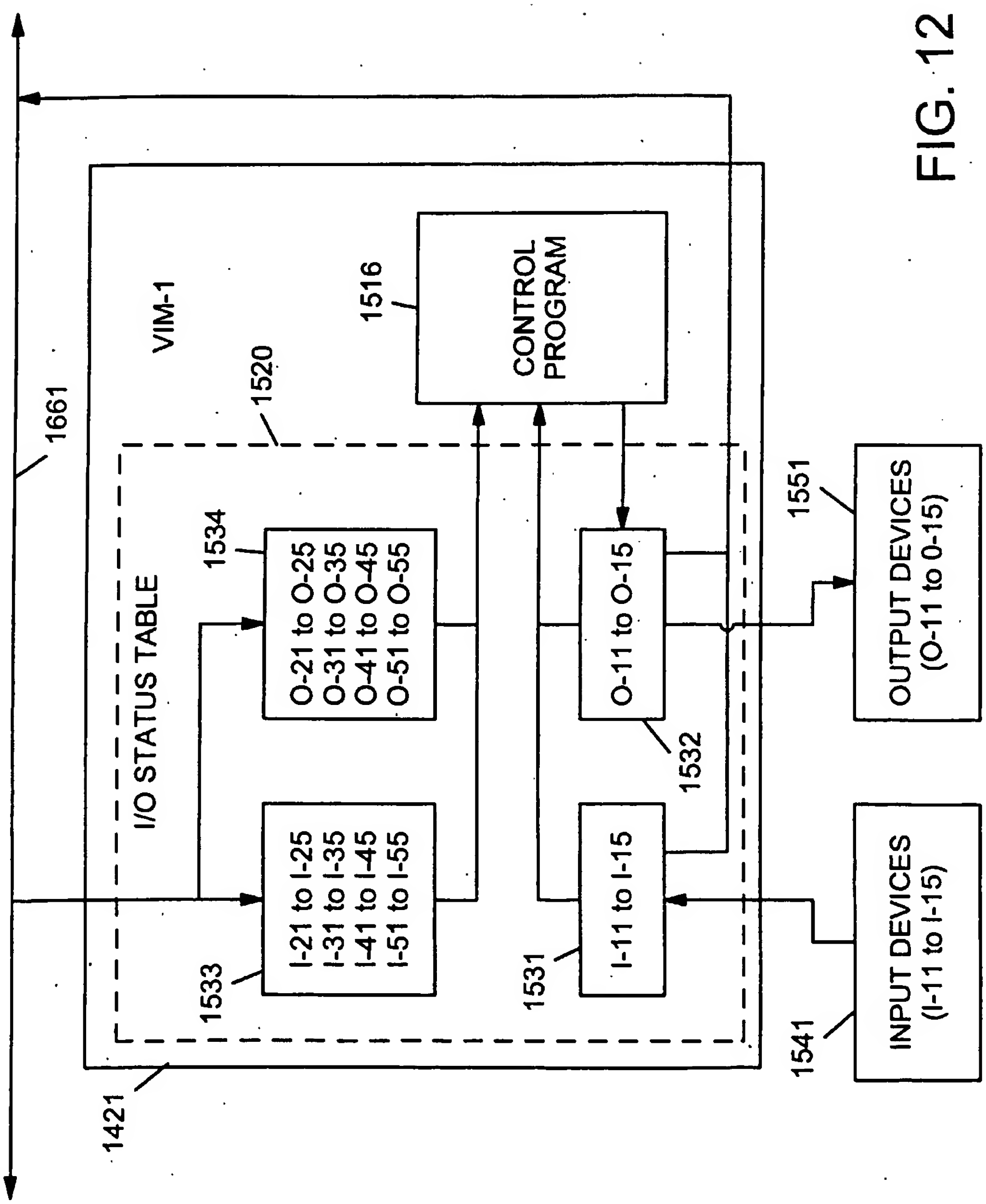

1661
1421
VIM-1
1520
I/O STATUS TABLE
1516
CONTROL PROGRAM
1534
O-21 to O-25
O-31 to O-35
O-41 to O-45
O-51 to O-55
1533
I-21 to I-25
I-31 to I-35
I-41 to I-45
I-51 to I-55
1531
I-11 to I-15
1532
O-11 to O-15
1551
OUTPUT DEVICES
(O-11 to 0-15)
1541
INPUT DEVICES
(I-11 to I-15)

FIG. 12

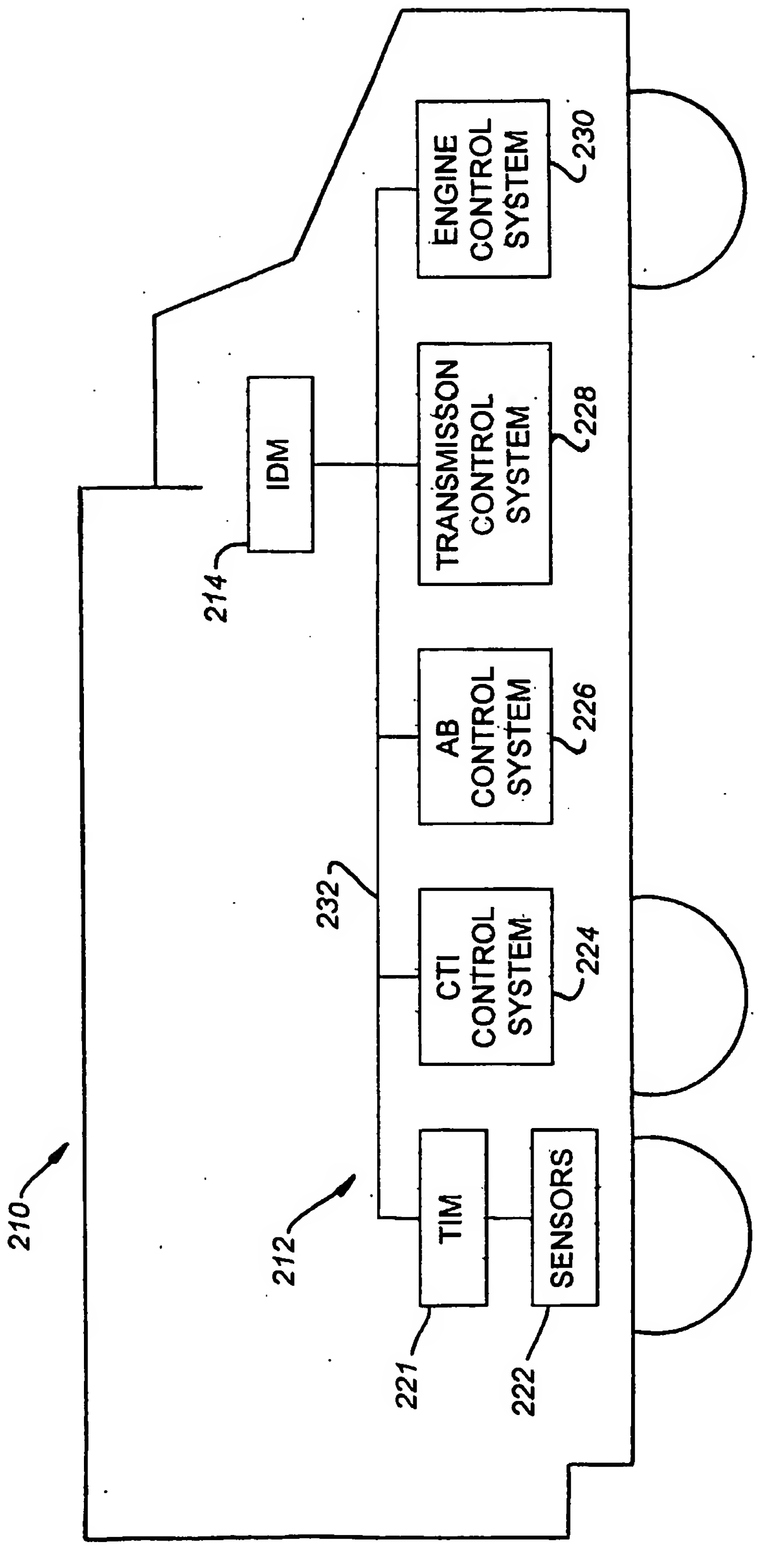

ENGINE CONTROL SYSTEM
230
IDM
214
TRANSMISSON CONTROL SYSTEM
228
AB CONTROL SYSTEM
226
232
CTI CONTROL SYSTEM
224
210
212
TIM
SENSORS
221
222

FIG. 13

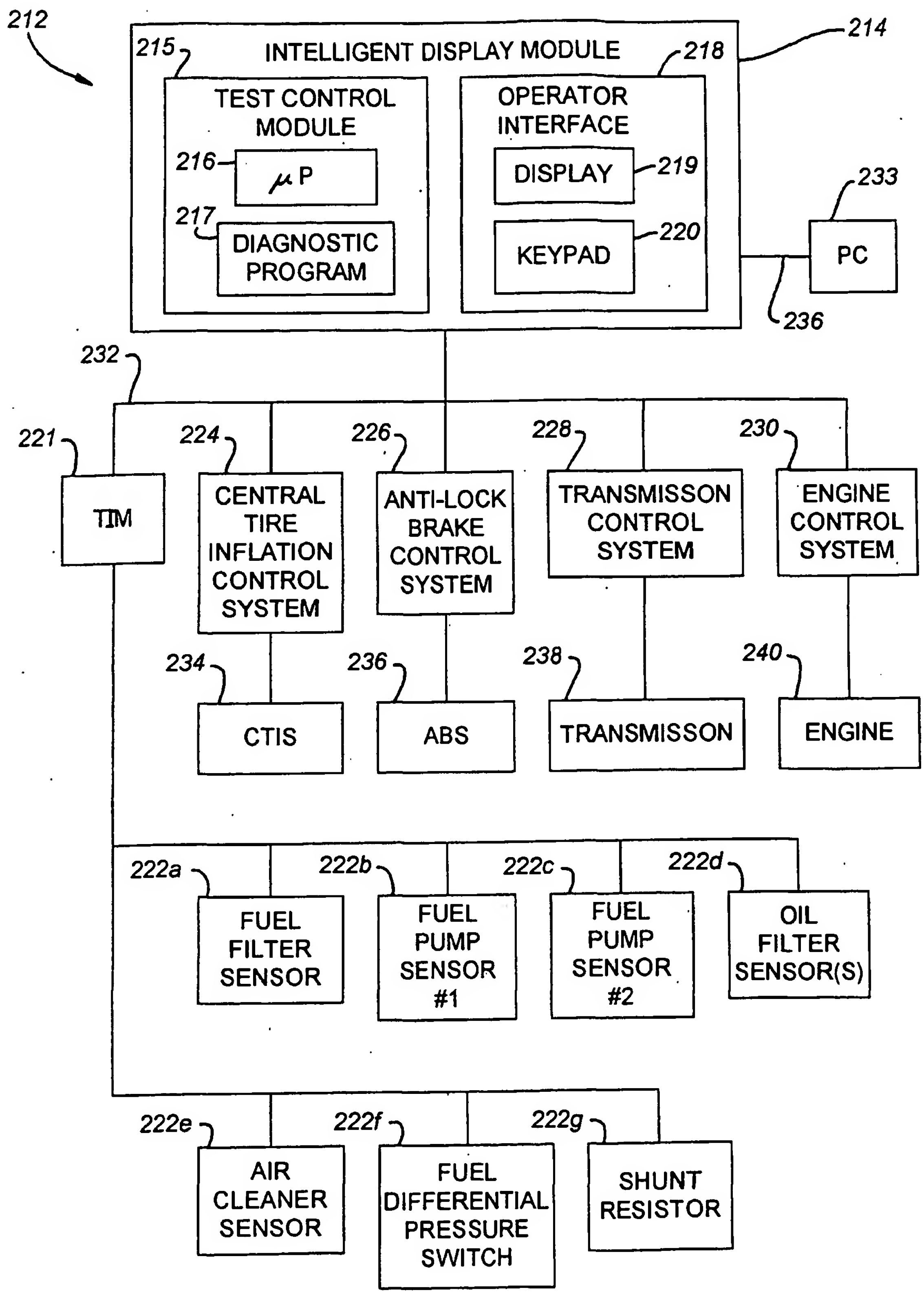
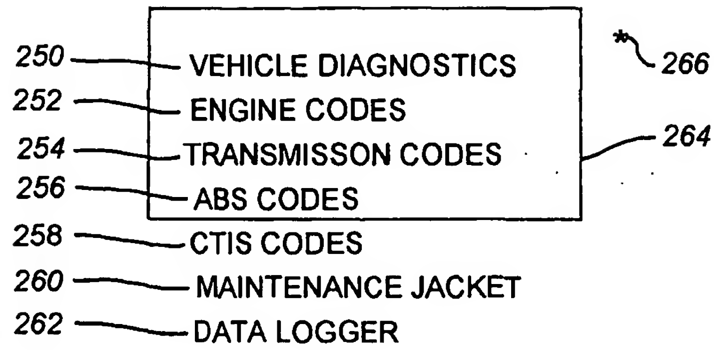
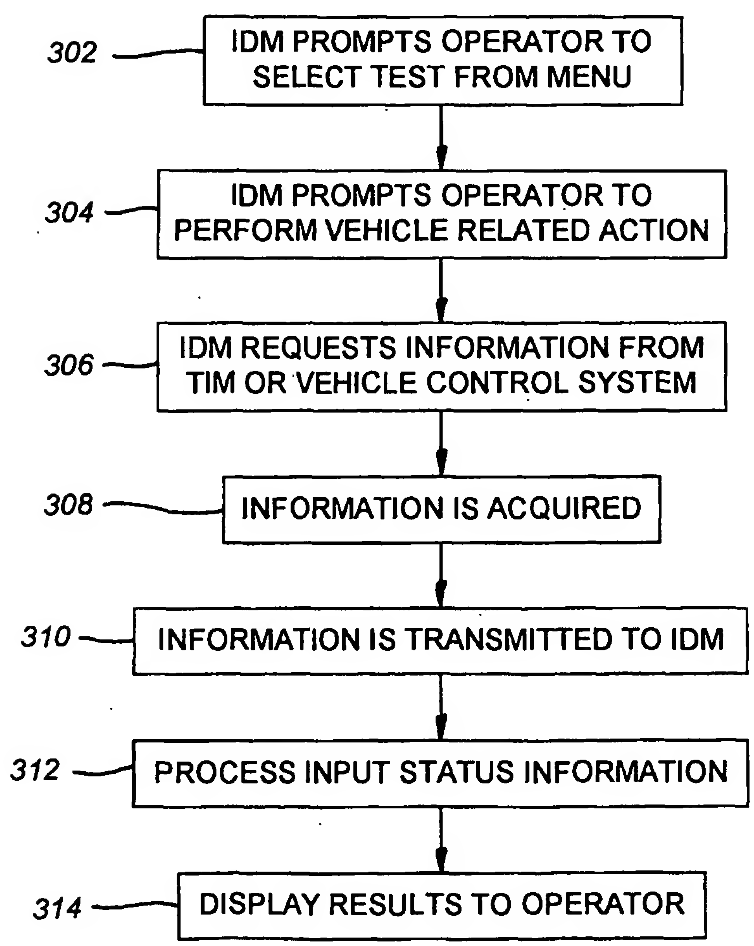

212
INTELLIGENT DISPLAY MODULE
214
215
TEST CONTROL MODULE
216
μP
217
DIAGNOSTIC PROGRAM
218
OPERATOR INTERFACE
DISPLAY
219
KEYPAD
220
233
PC
236
232
221
TIM
224
CENTRAL TIRE INFLATION CONTROL SYSTEM
226
ANTI-LOCK BRAKE CONTROL SYSTEM
228
TRANSMISSON CONTROL SYSTEM
230
ENGINE CONTROL SYSTEM
234
CTIS
236
ABS
238
TRANSMISSON
240
ENGINE
222a
FUEL FILTER SENSOR
222b
FUEL PUMP SENSOR #1
222c
FUEL PUMP SENSOR #2
222d
OIL FILTER SENSOR(S)
222e
AIR CLEANER SENSOR
222f
FUEL DIFFERENTIAL PRESSURE SWITCH
222g
SHUNT RESISTOR

FIG. 14



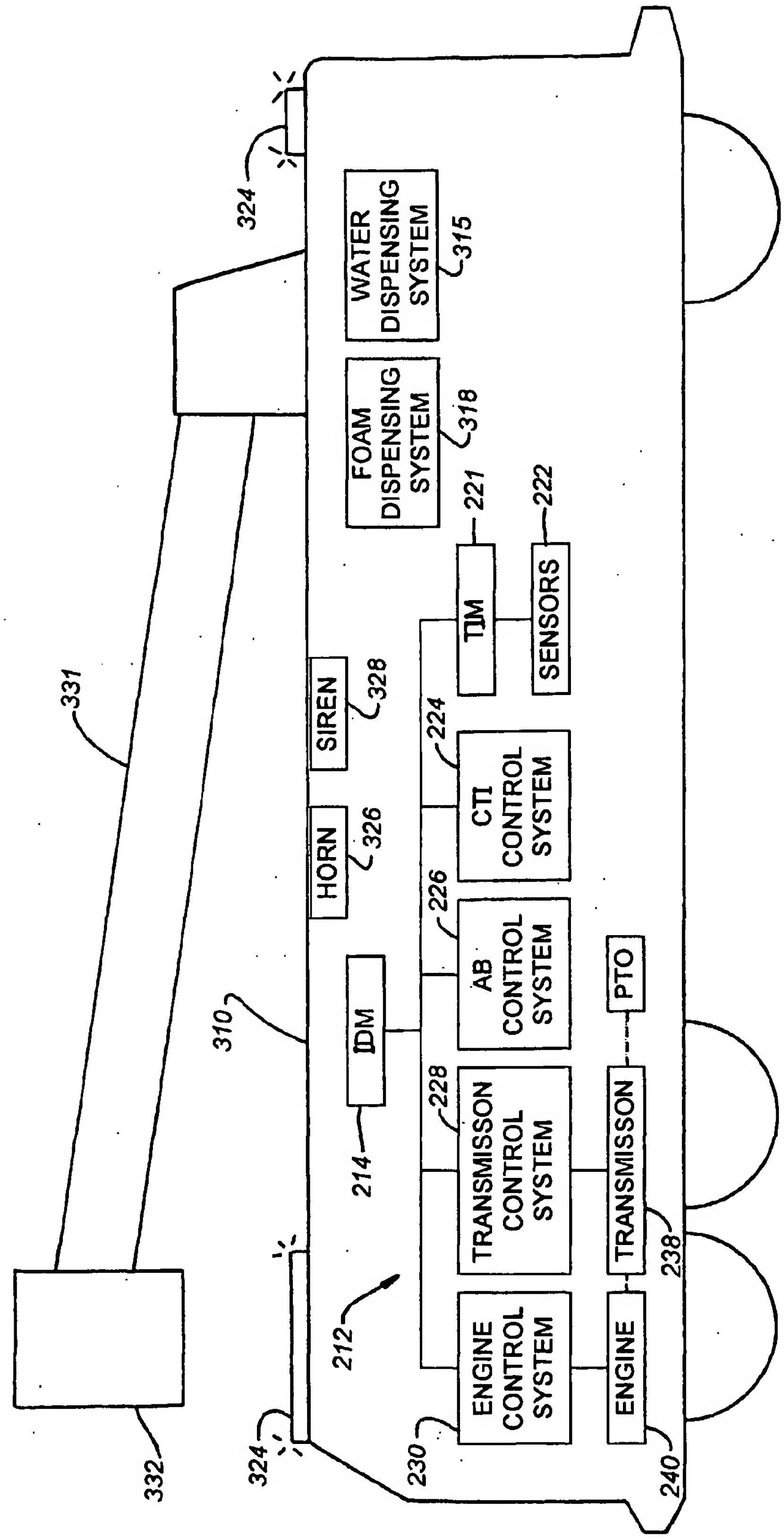
266
264
250 VEHICLE DIAGNOSTICS
252 ENGINE CODES
254 TRANSMISSON CODES
256 ABS CODES
258 CTIS CODES
260 MAINTENANCE JACKET
262 DATA LOGGER

FIG. 15



302 IDM PROMPTS OPERATOR TO SELECT TEST FROM MENU
304 IDM PROMPTS OPERATOR TO PERFORM VEHICLE RELATED ACTION
306 IDM REQUESTS INFORMATION FROM TIM OR VEHICLE CONTROL SYSTEM
308 INFORMATION IS ACQUIRED
310 INFORMATION IS TRANSMITTED TO IDM
312 PROCESS INPUT STATUS INFORMATION
314 DISPLAY RESULTS TO OPERATOR

FIG. 16



324
WATER DISPENSING SYSTEM
315
FOAM DISPENSING SYSTEM
318
221
222
TIM
SENSORS
331
SIREN
328
224
HORN
326
CTI CONTROL SYSTEM
226
AB CONTROL SYSTEM
PTO
310
IDM
228
TRANSMISSON CONTROL SYSTEM
TRANSMISSON
214
238
212
ENGINE CONTROL SYSTEM
ENGINE
332
324
230
240

FIG. 17

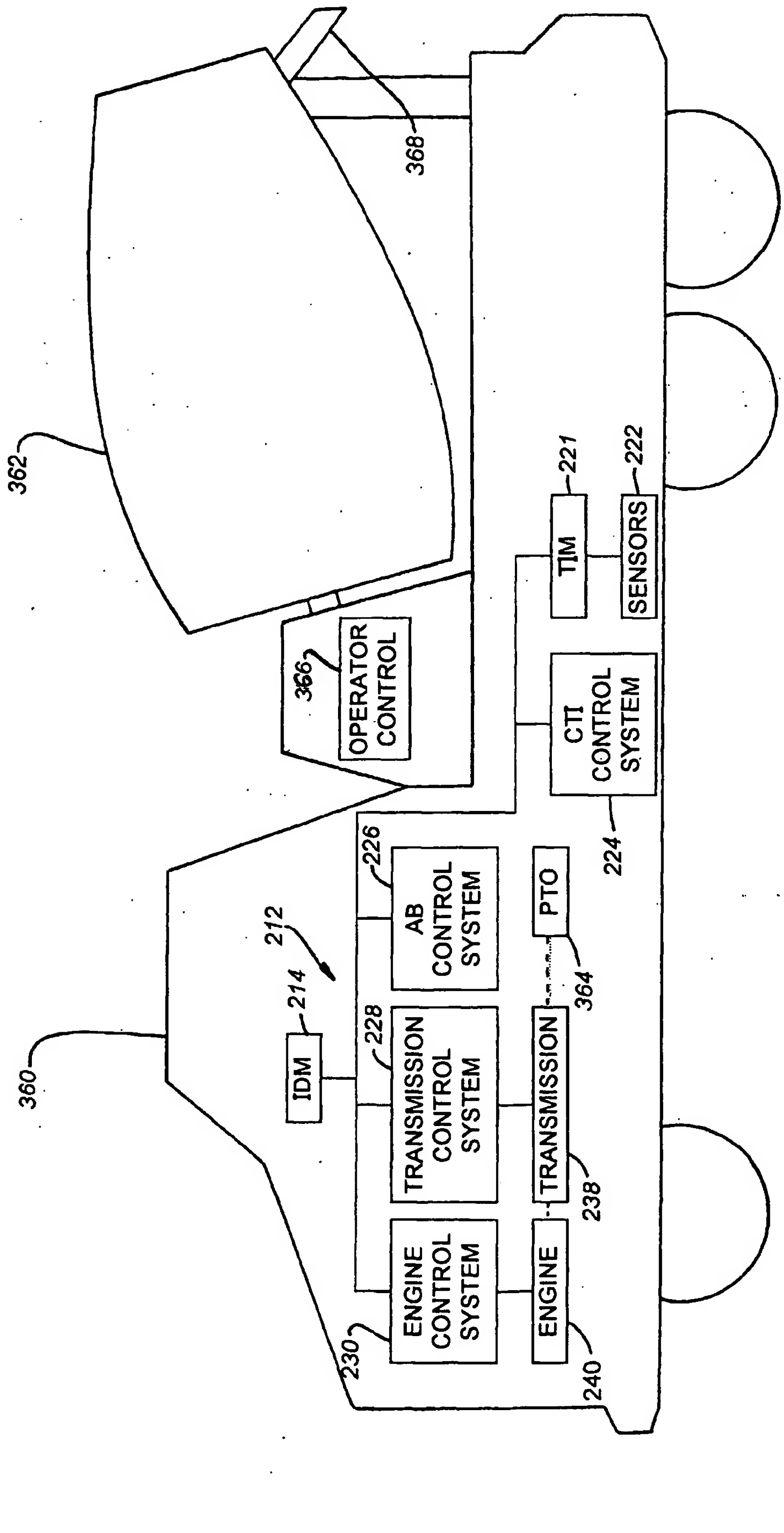
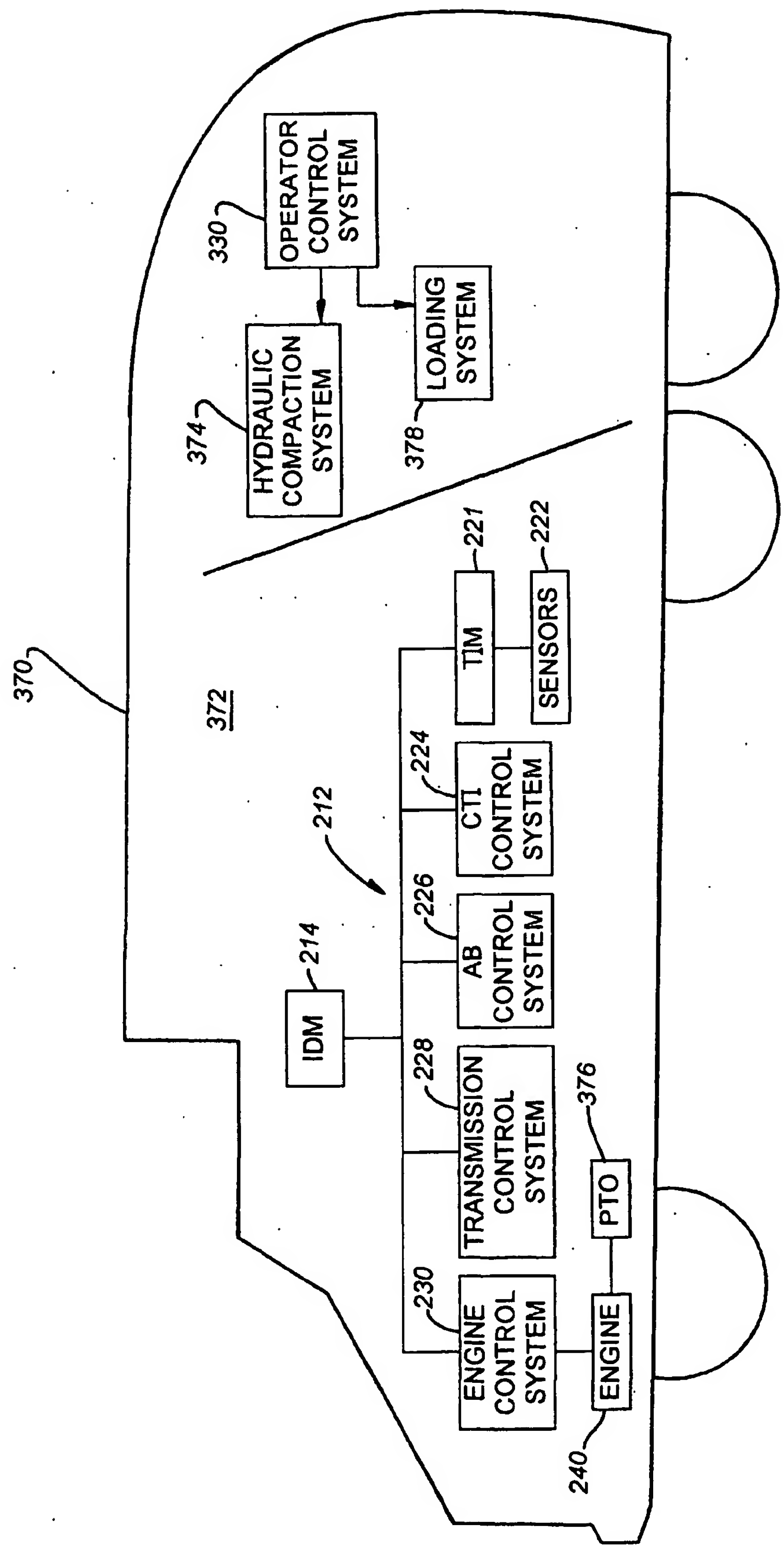
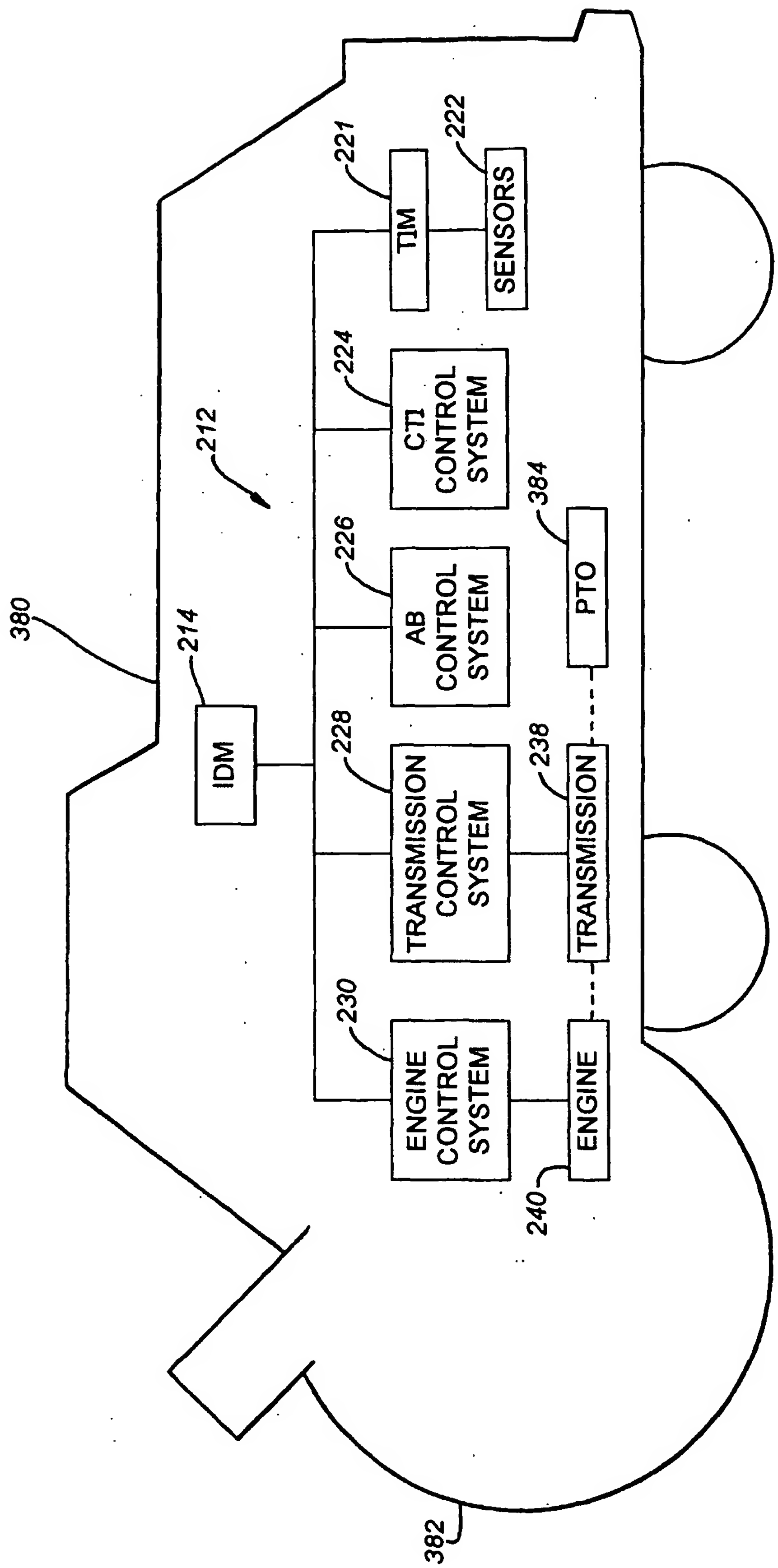

368
362
OPERATOR CONTROL
366
TIM
221
SENSORS
222
CTI CONTROL SYSTEM
224
AB CONTROL SYSTEM
226
212
214
IDM
228
TRANSMISSION CONTROL SYSTEM
PTO
364
TRANSMISSION
238
ENGINE CONTROL SYSTEM
230
ENGINE
240
360

FIG. 18



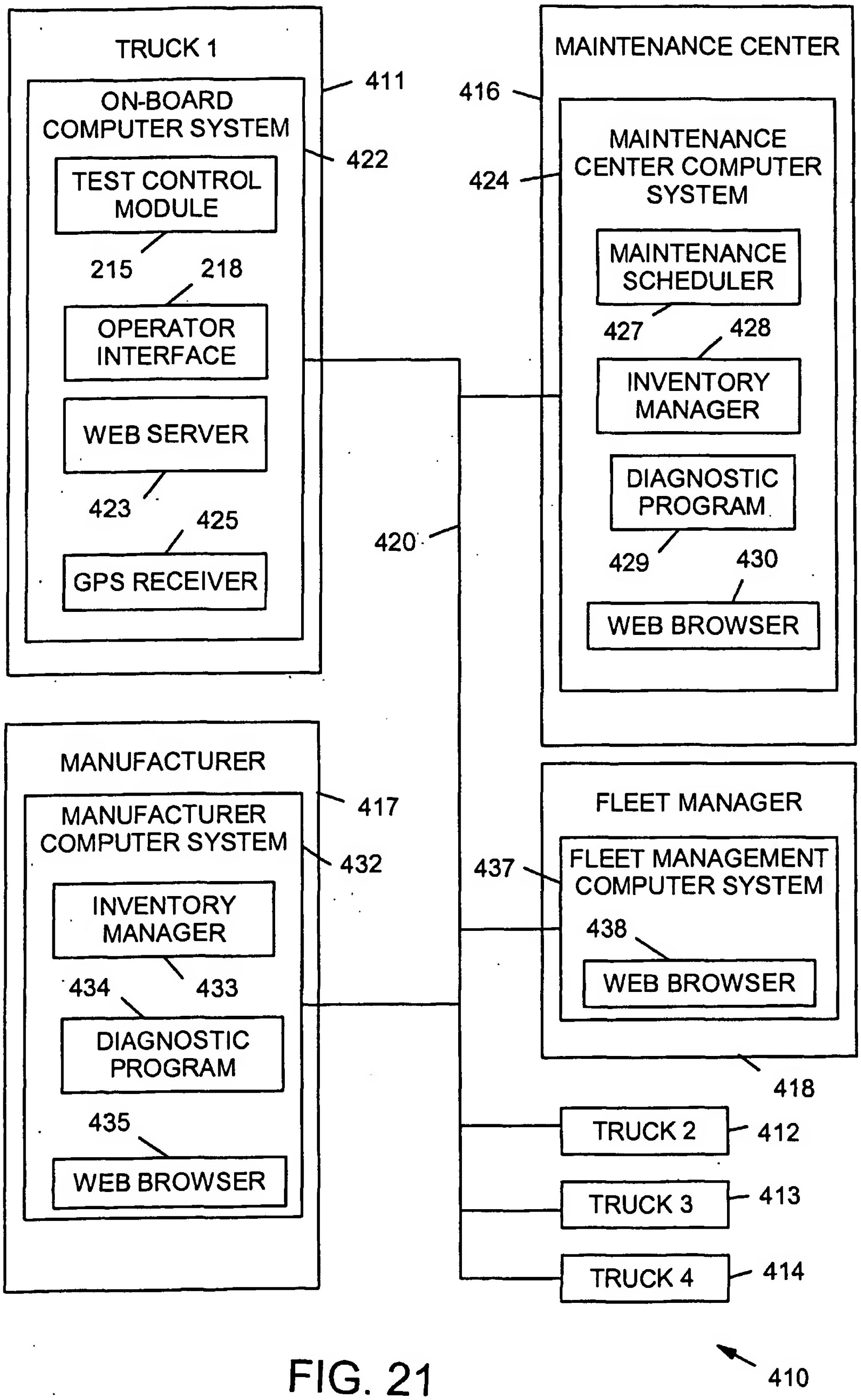
OPERATOR CONTROL SYSTEM
330
LOADING SYSTEM
378
HYDRAULIC COMPACTION SYSTEM
374
370
372
TIM
221
SENSORS
222
CTI CONTROL SYSTEM
224
212
AB CONTROL SYSTEM
226
IDM
214
TRANSMISSION CONTROL SYSTEM
228
PTO
376
ENGINE CONTROL SYSTEM
230
ENGINE
240

FIG. 19



221
TIM
222
SENSORS
224
CTI CONTROL SYSTEM
212
384
226
AB CONTROL SYSTEM
PTO
380
214
IDM
228
TRANSMISSION CONTROL SYSTEM
238
TRANSMISSION
230
ENGINE CONTROL SYSTEM
ENGINE
240
382

FIG. 20



TRUCK 1
ON-BOARD COMPUTER SYSTEM
TEST CONTROL MODULE
215
218
OPERATOR INTERFACE
WEB SERVER
423
425
GPS RECEIVER
411
422
MAINTENANCE CENTER
416
424
MAINTENANCE CENTER COMPUTER SYSTEM
MAINTENANCE SCHEDULER
427
428
INVENTORY MANAGER
DIAGNOSTIC PROGRAM
429
430
WEB BROWSER
420
MANUFACTURER
417
MANUFACTURER COMPUTER SYSTEM
432
INVENTORY MANAGER
434
433
DIAGNOSTIC PROGRAM
435
WEB BROWSER
FLEET MANAGER
437
FLEET MANAGEMENT COMPUTER SYSTEM
438
WEB BROWSER
418
TRUCK 2
412
TRUCK 3
413
TRUCK 4
414
410

FIG. 21

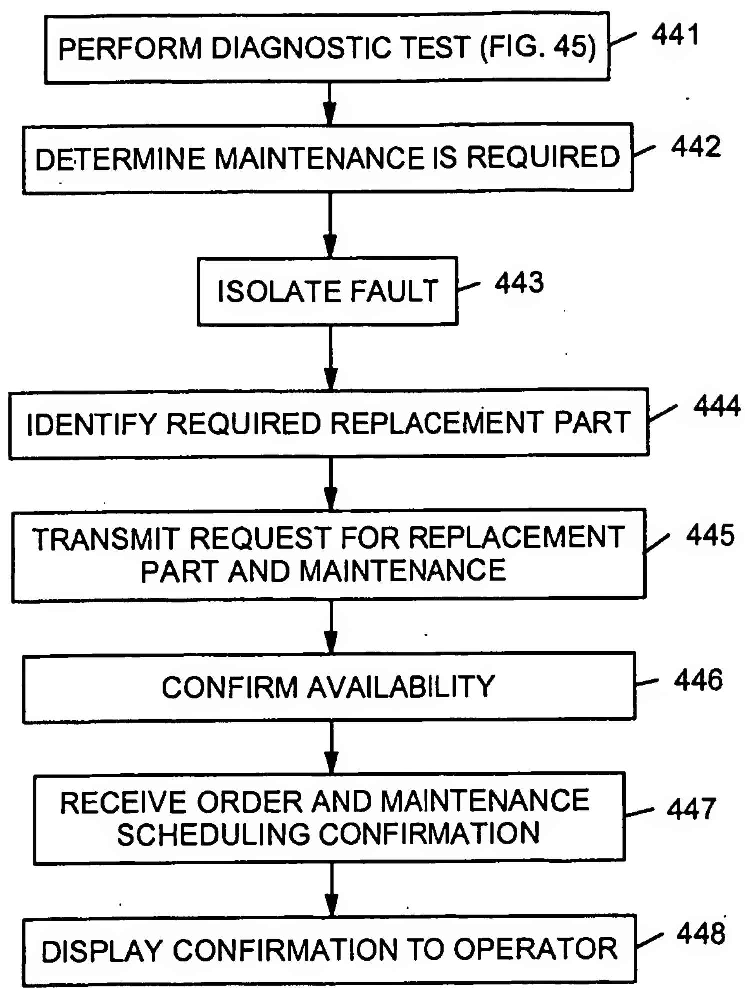

PERFORM DIAGNOSTIC TEST (FIG. 45)
441
DETERMINE MAINTENANCE IS REQUIRED
442
ISOLATE FAULT
443
IDENTIFY REQUIRED REPLACEMENT PART
444
TRANSMIT REQUEST FOR REPLACEMENT PART AND MAINTENANCE
445
CONFIRM AVAILABILITY
446
RECEIVE ORDER AND MAINTENANCE SCHEDULING CONFIRMATION
447
DISPLAY CONFIRMATION TO OPERATOR
448

FIG. 22

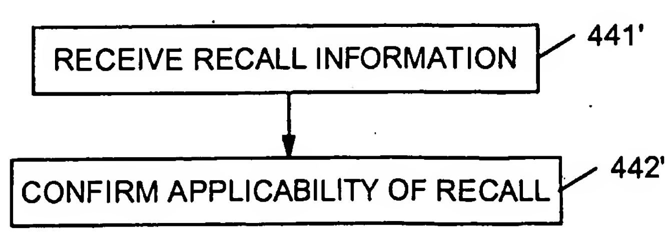

RECEIVE RECALL INFORMATION
441'
CONFIRM APPLICABILITY OF RECALL
442'

FIG. 24

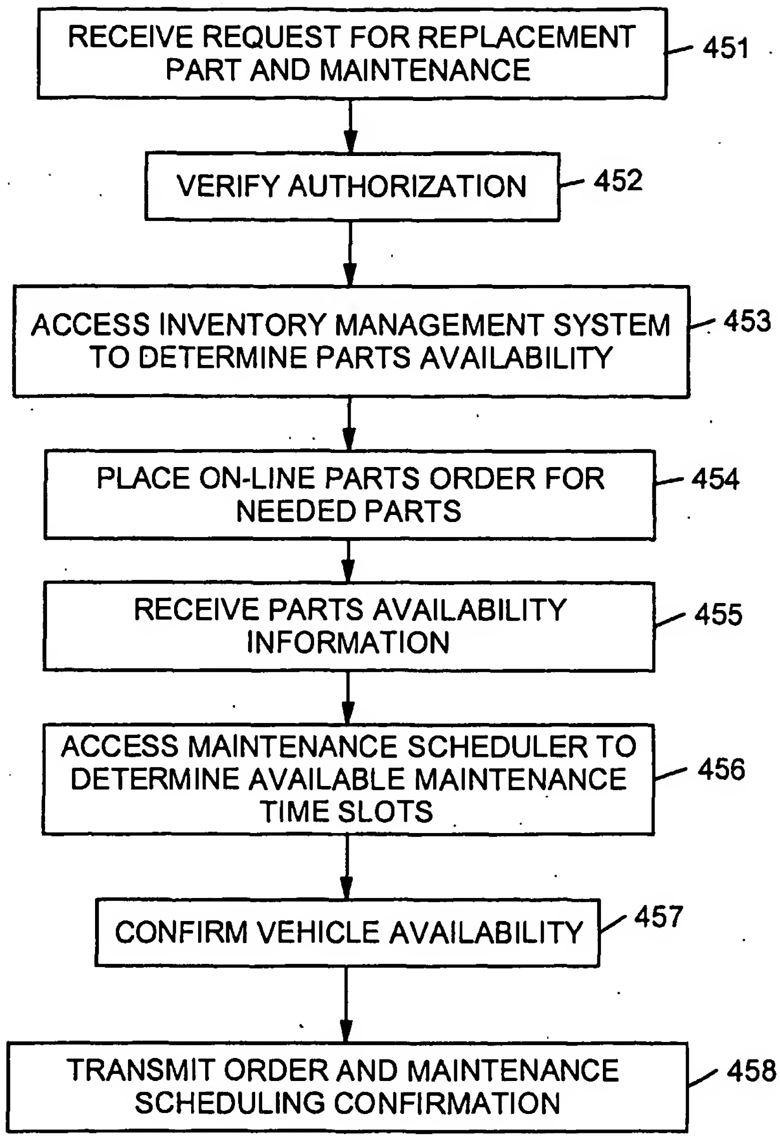

RECEIVE REQUEST FOR REPLACEMENT PART AND MAINTENANCE
451
VERIFY AUTHORIZATION
452
ACCESS INVENTORY MANAGEMENT SYSTEM TO DETERMINE PARTS AVAILABILITY
453
PLACE ON-LINE PARTS ORDER FOR NEEDED PARTS
454
RECEIVE PARTS AVAILABILITY INFORMATION
455
ACCESS MAINTENANCE SCHEDULER TO DETERMINE AVAILABLE MAINTENANCE TIME SLOTS
456
CONFIRM VEHICLE AVAILABILITY
457
TRANSMIT ORDER AND MAINTENANCE SCHEDULING CONFIRMATION
458

FIG. 23

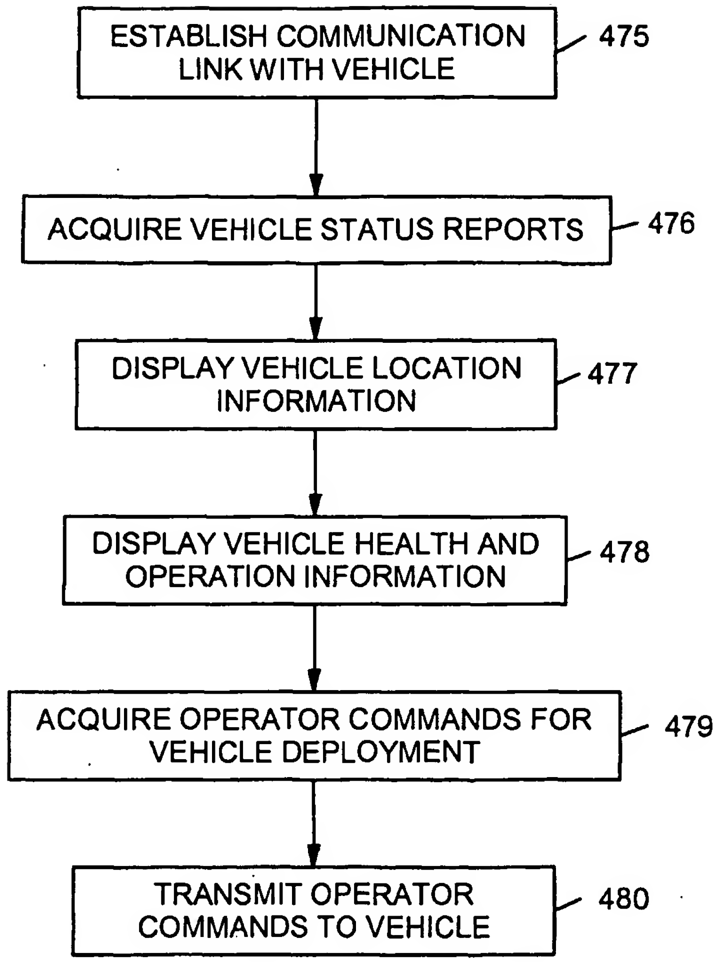

ESTABLISH COMMUNICATION LINK WITH VEHICLE
475
ACQUIRE VEHICLE STATUS REPORTS
476
DISPLAY VEHICLE LOCATION INFORMATION
477
DISPLAY VEHICLE HEALTH AND OPERATION INFORMATION
478
ACQUIRE OPERATOR COMMANDS FOR VEHICLE DEPLOYMENT
479
TRANSMIT OPERATOR COMMANDS TO VEHICLE
480

FIG. 25

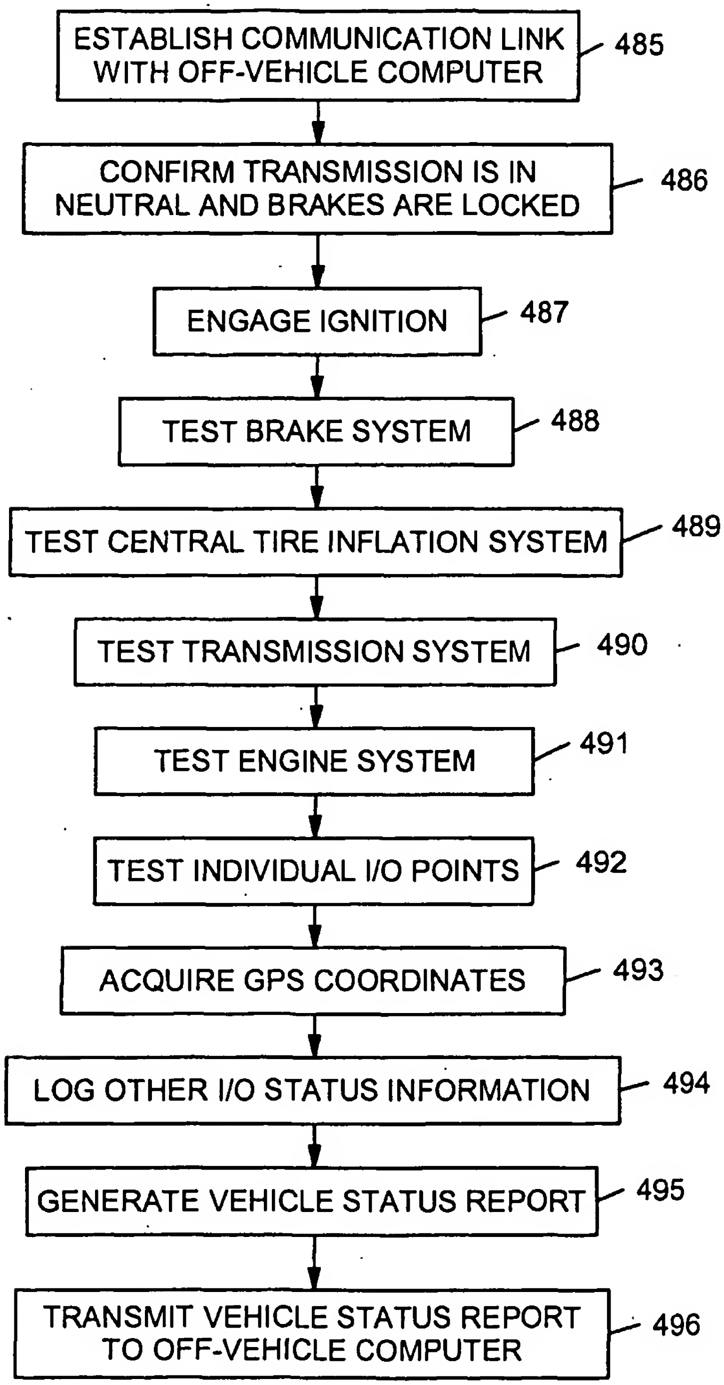

ESTABLISH COMMUNICATION LINK WITH OFF-VEHICLE COMPUTER
485
CONFIRM TRANSMISSION IS IN NEUTRAL AND BRAKES ARE LOCKED
486
ENGAGE IGNITION
487
TEST BRAKE SYSTEM
488
TEST CENTRAL TIRE INFLATION SYSTEM
489
TEST TRANSMISSION SYSTEM
490
TEST ENGINE SYSTEM
491
TEST INDIVIDUAL I/O POINTS
492
ACQUIRE GPS COORDINATES
493
LOG OTHER I/O STATUS INFORMATION
494
GENERATE VEHICLE STATUS REPORT
495
TRANSMIT VEHICLE STATUS REPORT TO OFF-VEHICLE COMPUTER
496

FIG. 26

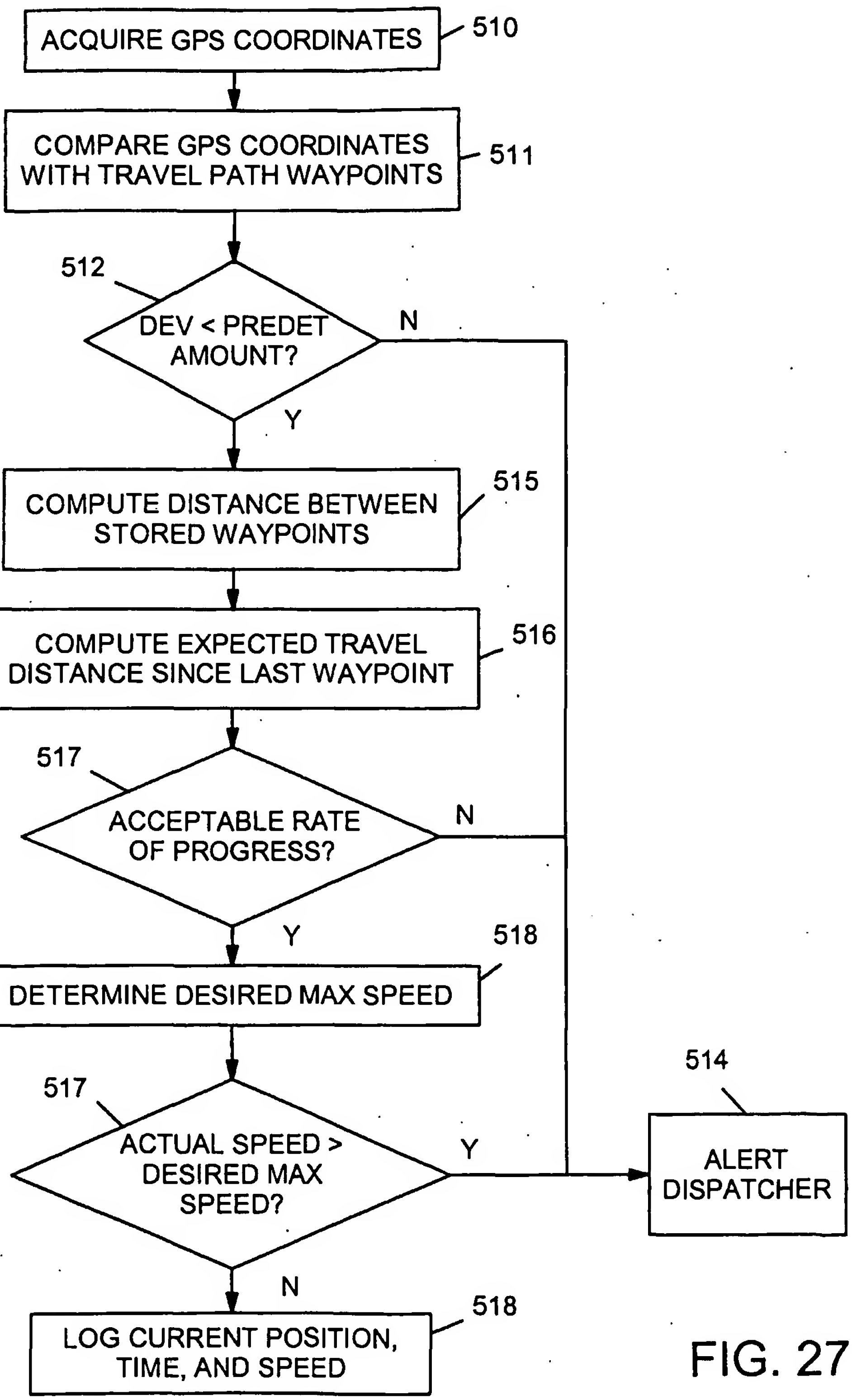

ACQUIRE GPS COORDINATES
510
COMPARE GPS COORDINATES WITH TRAVEL PATH WAYPOINTS
511
512
DEV < PREDET AMOUNT?
N
Y
COMPUTE DISTANCE BETWEEN STORED WAYPOINTS
515
COMPUTE EXPECTED TRAVEL DISTANCE SINCE LAST WAYPOINT
516
517
ACCEPTABLE RATE OF PROGRESS?
N
Y
518
DETERMINE DESIRED MAX SPEED
514
517
ACTUAL SPEED > DESIRED MAX SPEED?
Y
ALERT DISPATCHER
N
518
LOG CURRENT POSITION, TIME, AND SPEED

FIG. 27

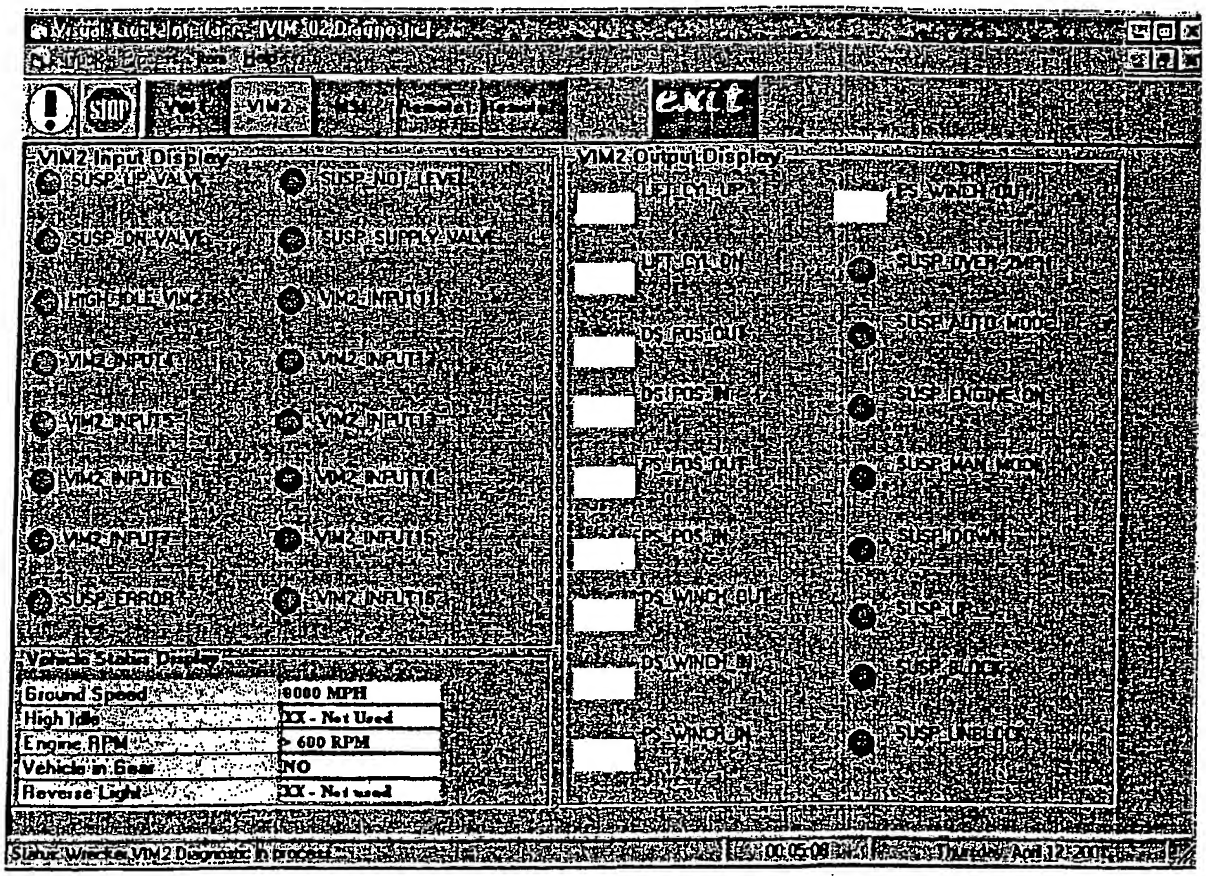

VIM2 Input Display
SUSP_UP_VALVE
SUSP_NOT_LEVEL
SUSP_DN_VALVE
SUSP_SUPPLY_VALVE
VIM2 INPUT4
VIM2 INPUT5
VIM2 INPUT6
VIM2 INPUT7
SUSP_ERROR
VIM2 INPUT11
VIM2 INPUT14
VIM2 INPUT15
VIM2 INPUT16
VIM2 Output Display
LIFT_CYL_UP
LIFT_CYL_DN
DS_POS_OUT
DS_POS_IN
PS_POS_OUT
PS_POS_IN
DS_WINCH_OUT
DS_WINCH_IN
PS_WINCH_IN
PS_WINCH_OUT
SUSP_AUTO_MODE
SUSP_ENGINE_ON
SUSP_DOWN
SUSP_UP
SUSP_BLOCK
SUSP_UNBLOCK
Vehicle Status Display
Ground Speed
0000 MPH
High Idle
XX - Not Used
Engine RPM
> 600 RPM
Vehicle in Gear
NO
Reverse Light
XX - Not used
exit
VIM2
Status: Wrecker VIM2 Diagnostic in process
00:05:08

FIG. 28

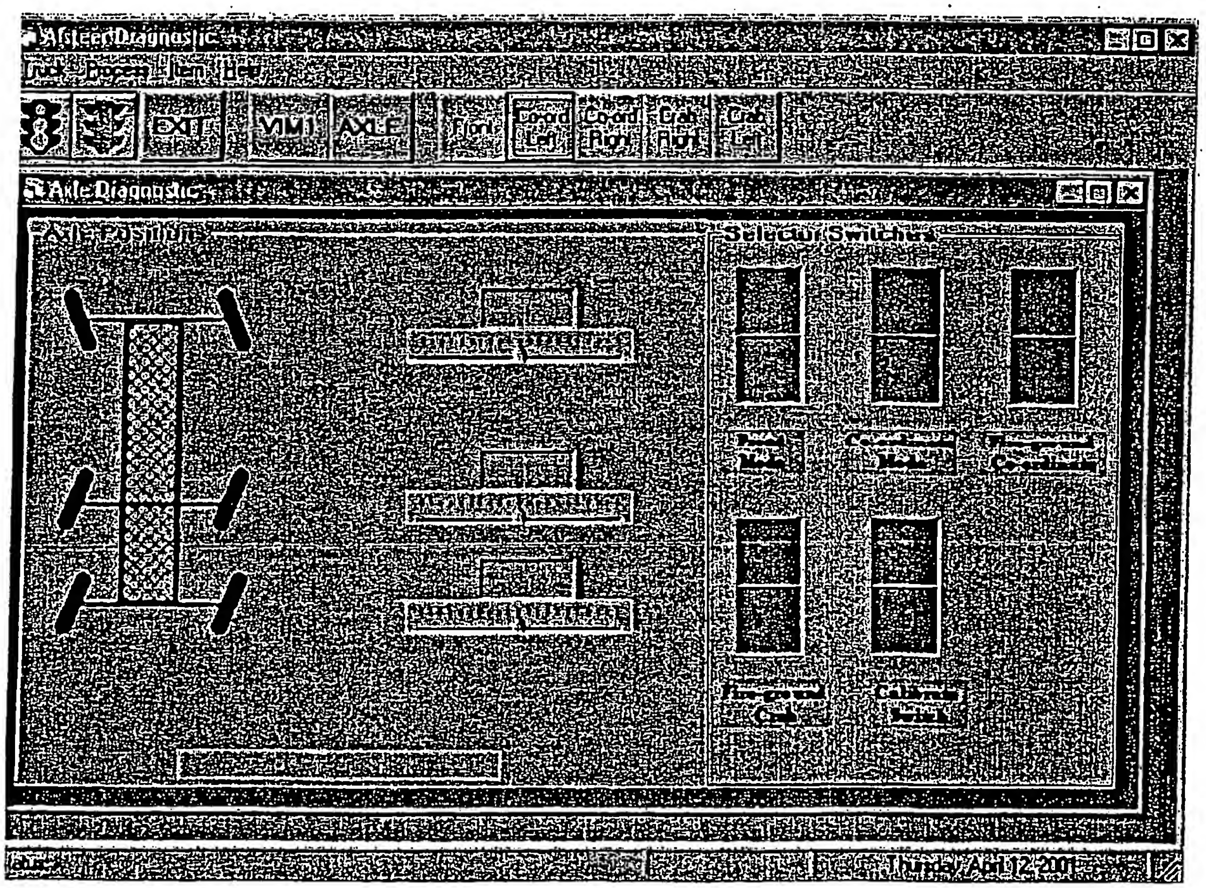


FIG. 29

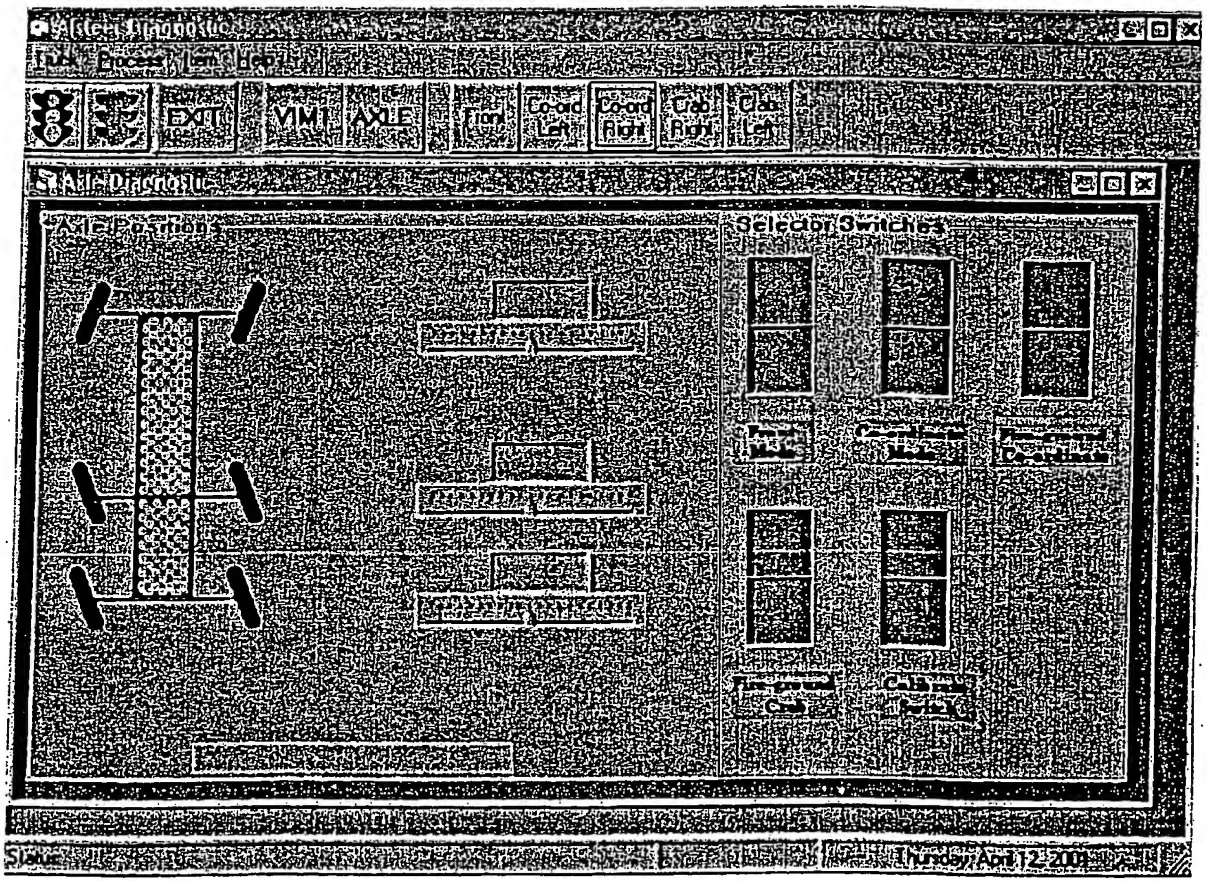

EXIT
VIMT
AXLE
Axle Diagnostic
Axle Positions
Selector Switches
Thursday, April 12, 2001

FIG. 30

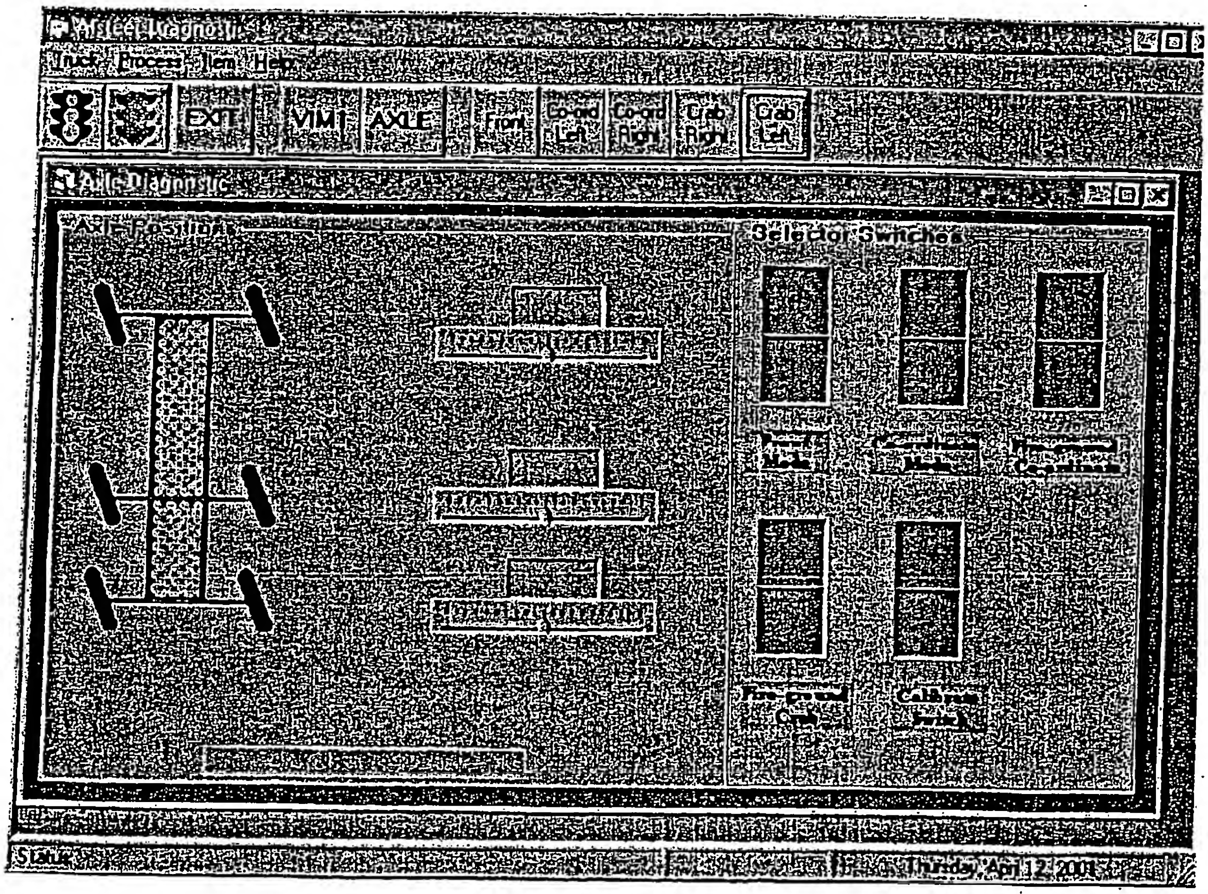

EXIT
VIM
AXLE
Front
Co-ord Left
Co-ord Right
Crab Right
Crab Left
Axle Diagnostic
Selector Switches
Status
Thursday, April 12, 2001

FIG. 31

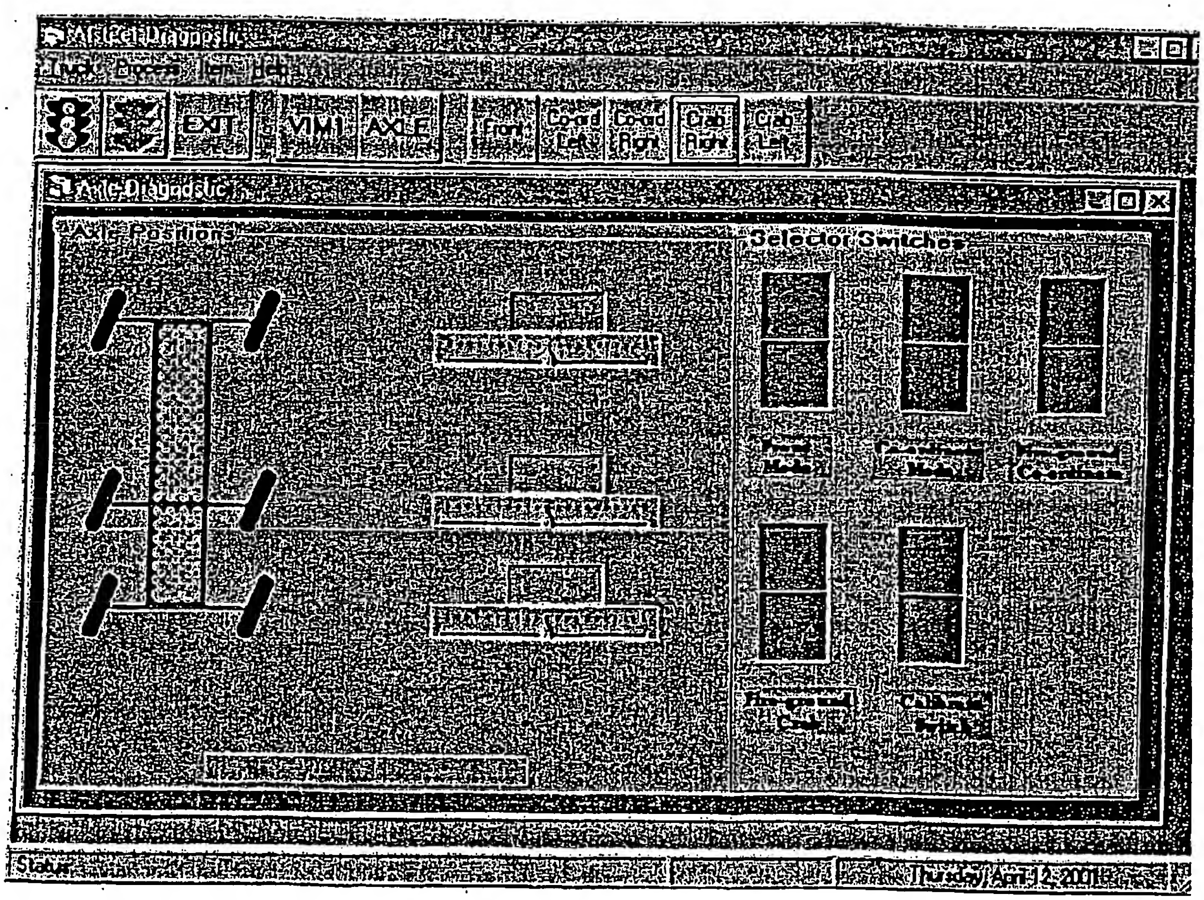

EXIT
VIM1
AXLE
Front
Co-ord Left
Co-ord Right
Crab Right
Crab Left
Axle Position
Selector Switches
Status
Thursday, April 12, 2001

FIG. 32

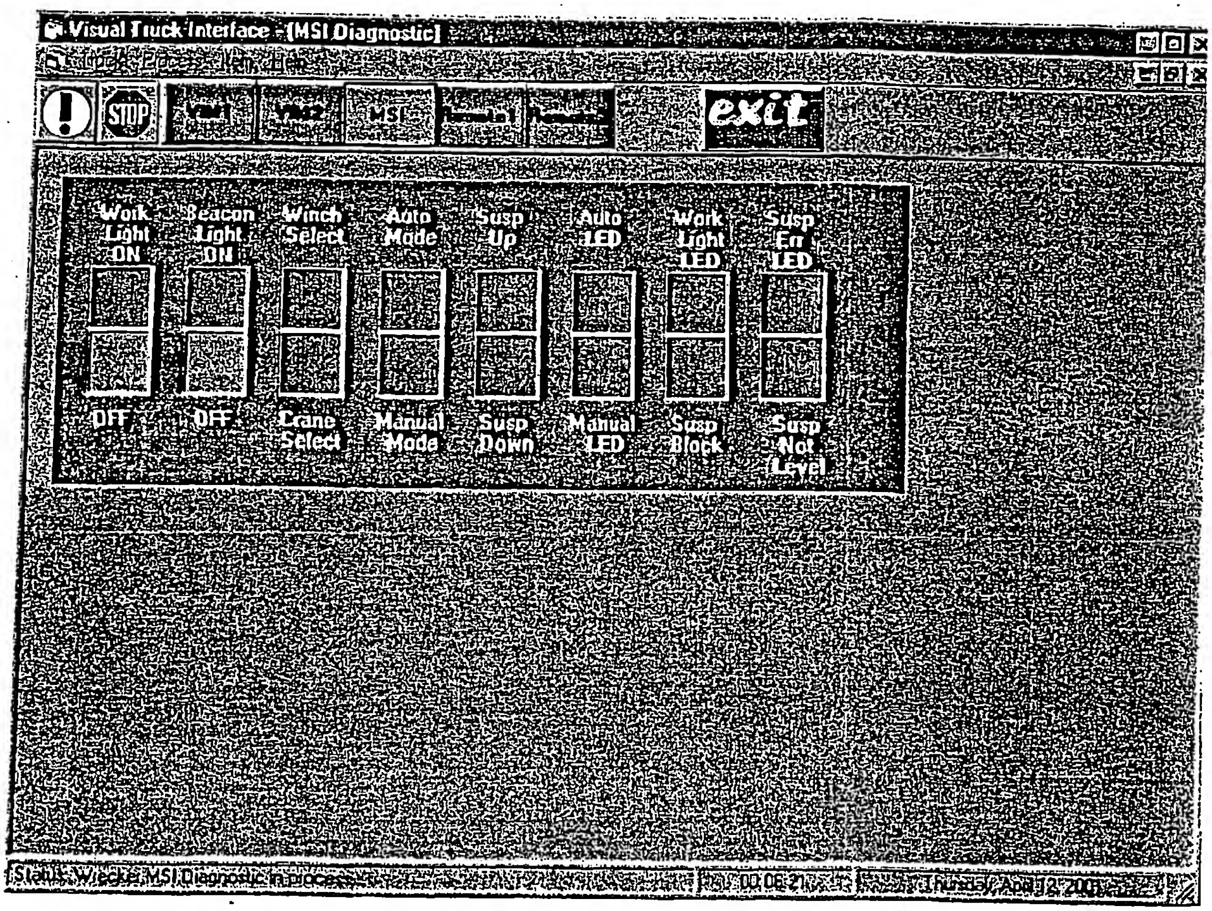

Visual Truck Interface - [MSI Diagnostic]
STOP
MSI
exit
Work Light ON
Beacon Light ON
Winch Select
Auto Mode
Susp Up
Auto LED
Work Light LED
Susp Err LED
OFF
OFF
Crane Select
Manual Mode
Susp Down
Manual LED
Susp Block
Susp Not Level

FIG. 33

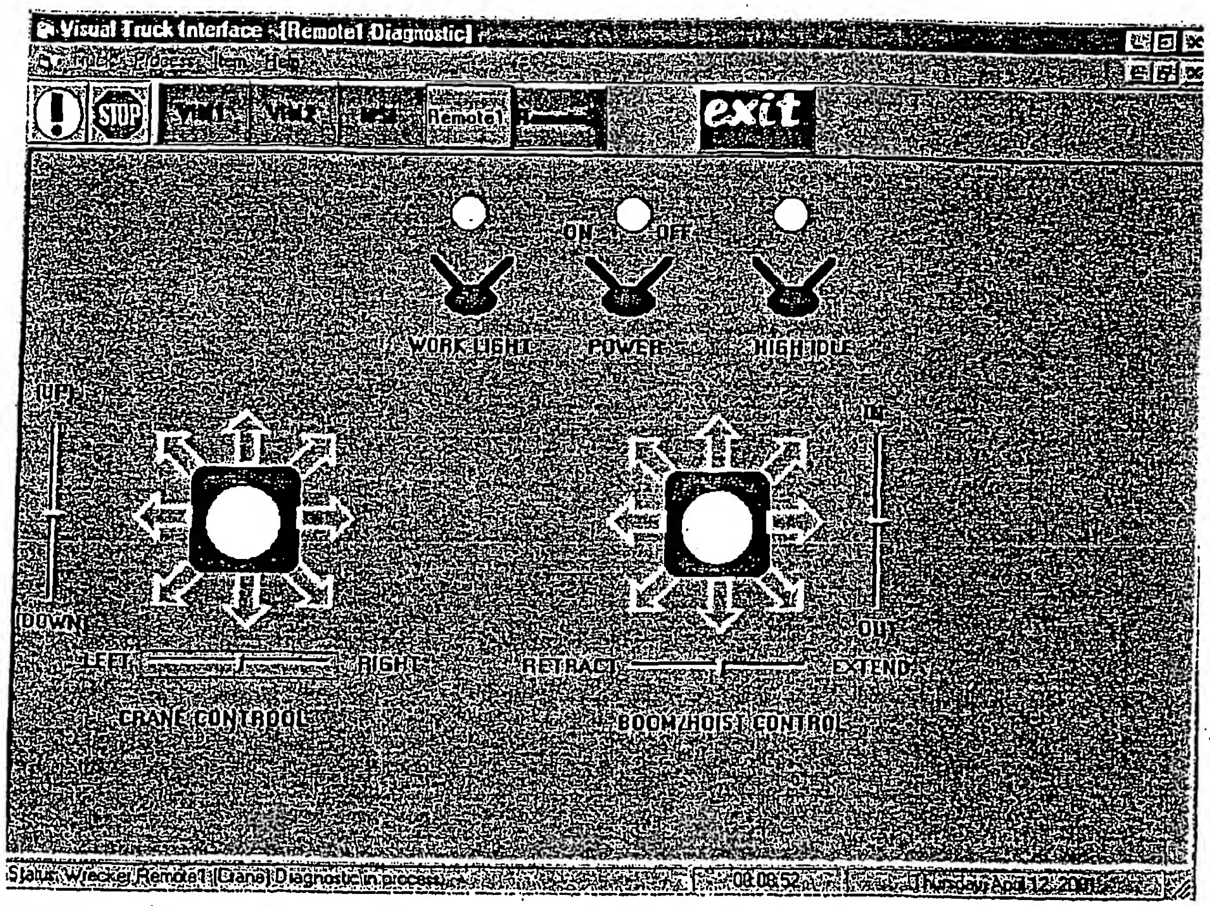

Visual Truck Interface - [Remote1 Diagnostic]
STOP
Remote1
exit
ON
OFF
WORK LIGHT
POWER
HIGH IDLE
UP
DOWN
OUT
LEFT
RIGHT
RETRACT
EXTEND
CRANE CONTROL
BOOM/HOIST CONTROL

FIG. 34

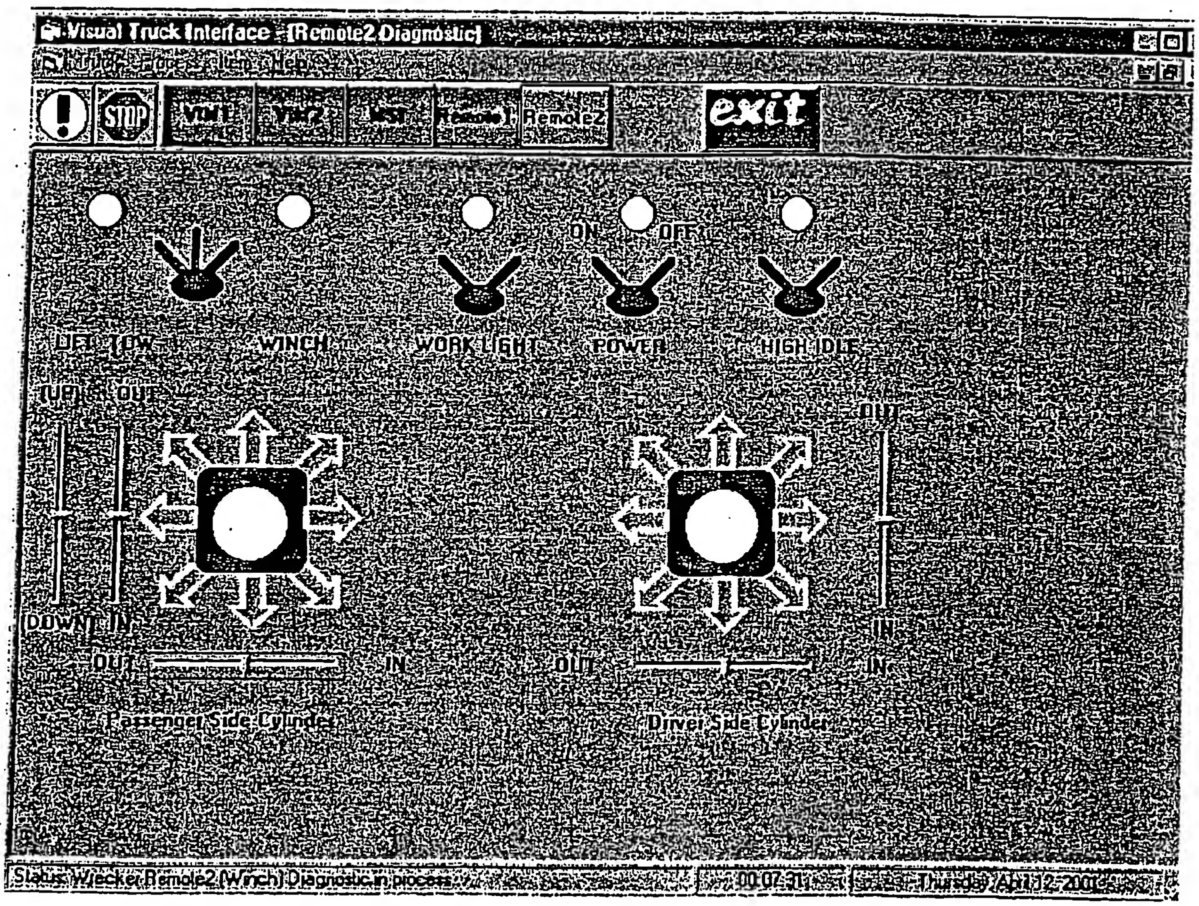

Visual Truck Interface - [Remote2 Diagnostic]
STOP
Remote1
Remote2
exit
ON
OFF
WINCH
WORK LIGHT
POWER
HIGH IDLE
OUT
DOWN
IN
OUT
IN
OUT
IN
OUT
IN
Passenger Side Cylinder
Driver Side Cylinder
00:07:31

FIG. 35

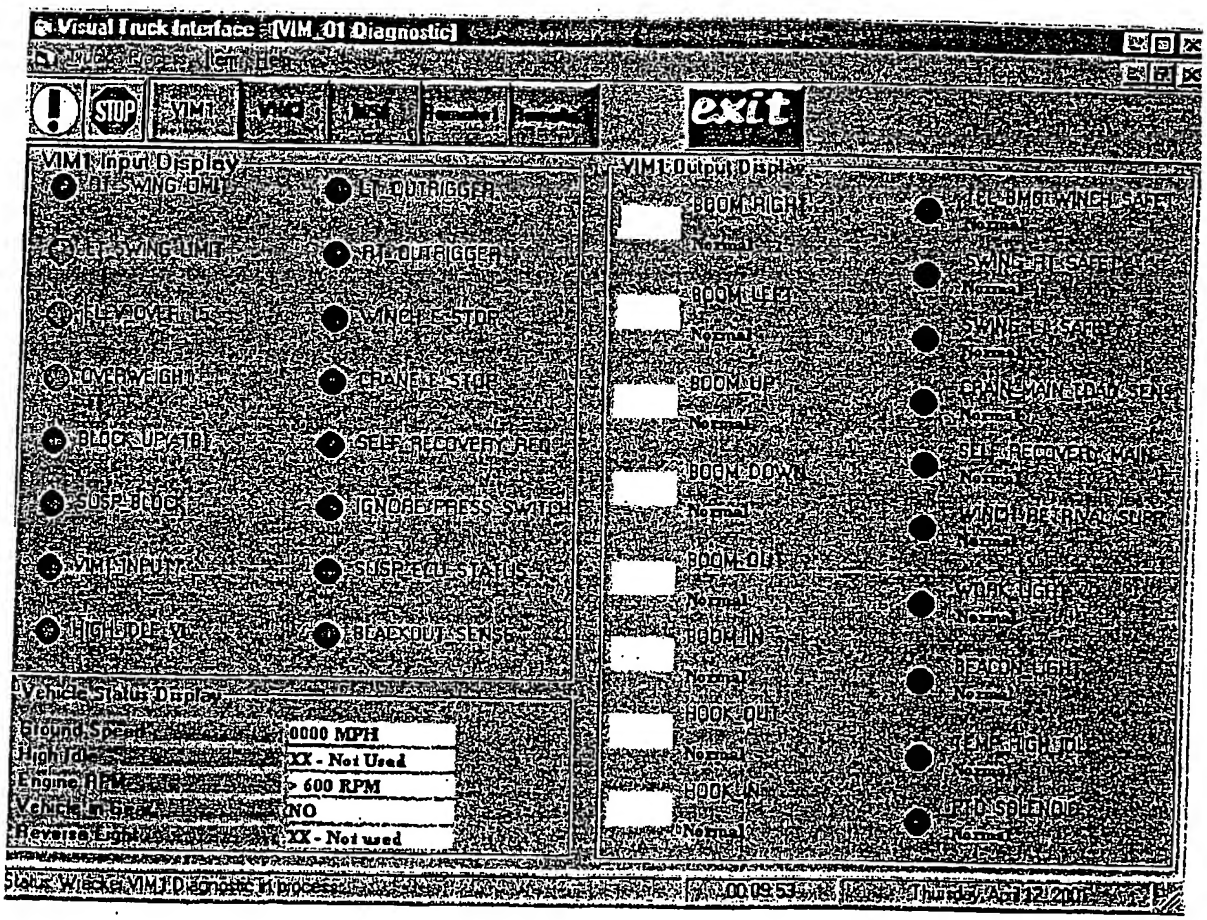

Visual Truck Interface - [VIM_01 Diagnostic]
exit
VIM1 Input Display
VIM1 Output Display
BOOM RIGHT
BOOM UP
BOOM DOWN
BOOM OUT
BOOM IN
HOOK OUT
HOOK IN
Normal
Vehicle Status Display
Ground Speed
Engine RPM
Vehicle in Gear
0000 MPH
XX - Not Used
> 600 RPM
NO
XX - Not used
00:09:53
Thursday, April 12, 2001

FIG. 36

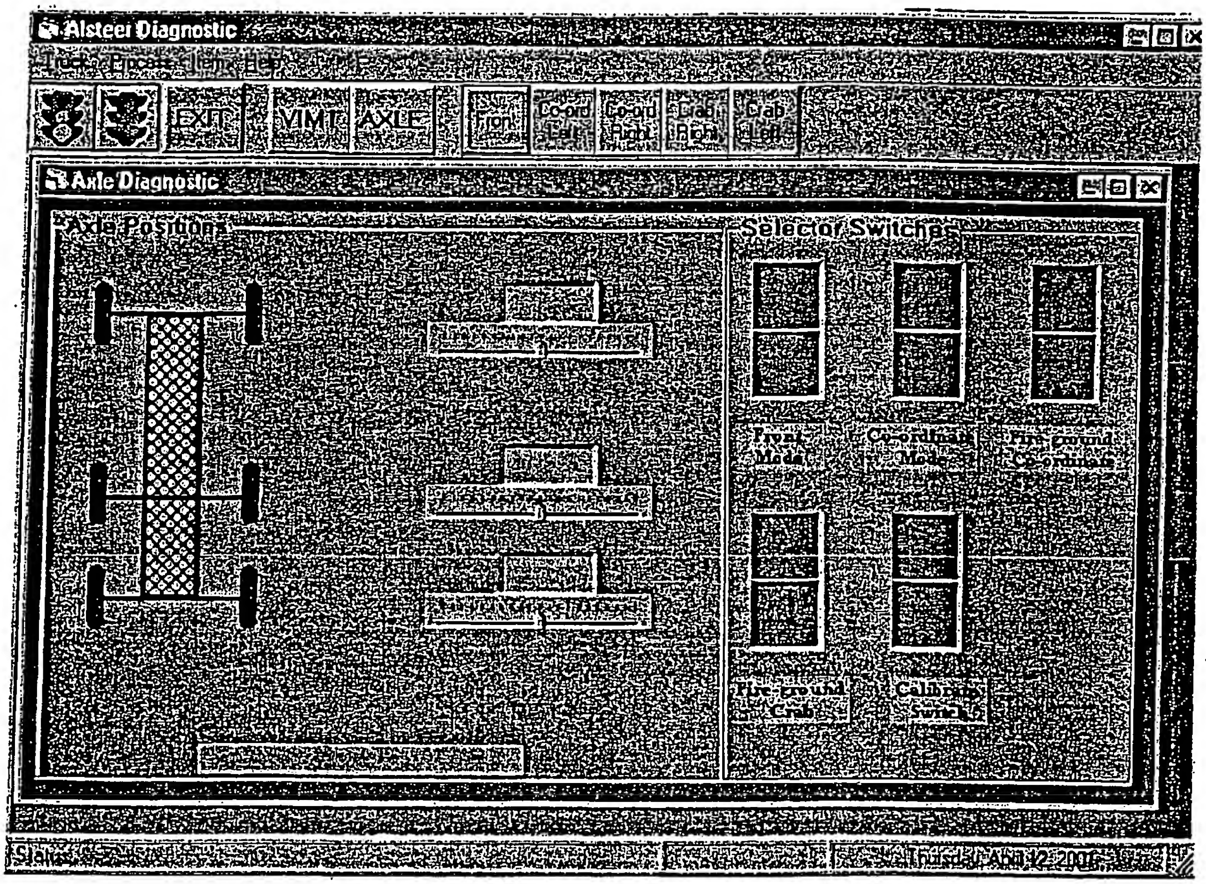

Alsteer Diagnostic
EXIT
VIMT
AXLE
Axle Diagnostic
Axle Position
Selector Switches

FIG. 37

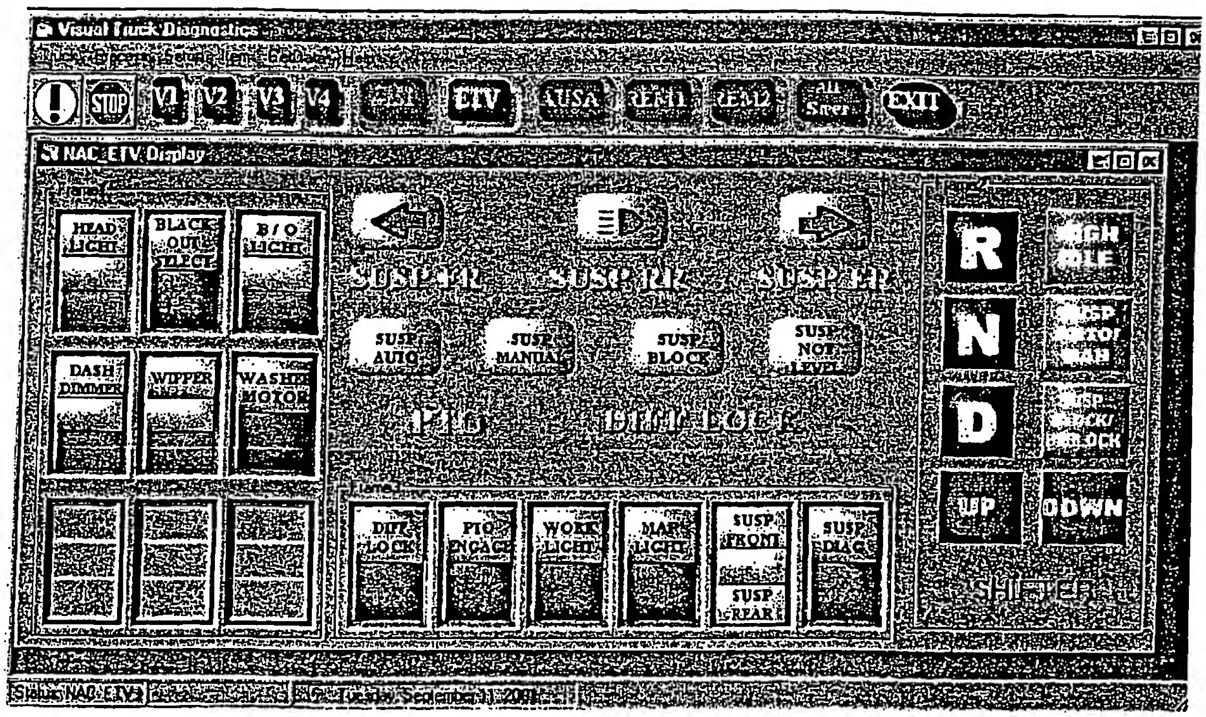

Visual Truck Diagnostics
STOP
V1
V2
V3
V4
ETV
EXIT
NAC ETV Display
HEAD LIGHT
BLACK OUT
B/O LIGHT
DASH DIMMER
WIPPER
WASHER MOTOR
SUSP AUTO
SUSP MANUAL
SUSP BLOCK
SUSP NOT LEVEL
DIFF LOCK
PTO ENGAGE
WORK LIGHT
MAR LIGHT
SUSP FRONT
SUSP REAR
SUSP DIAG
R
N
D
UP
DOWN

FIG. 38